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ABSTRACT

The National Aeronautics and Space Administration (NASA) seeks to promote broader and accelerated use of their bank of technical knowledge. This publication is intended to heighten public awareness of the technology available for use and its potential for economic and social benefit to the United States. Section 1 outlines NASA's mainline programs including space operations, aviation technology, space probing, and commerical use of space. Section 2 contains a representative selection of spinoff products and processes and describes the NASA technology from which these transfers were derived. Section 3 details the mechanisms NASA employs to foster technology utilization and stimulate interest among prospective users of the technology. It also contains a brief resume of NASA's efforts in related fields. An appendix to Section 3 lists contact sources for further information about the technology utilization and space commercialization programs. (YP)

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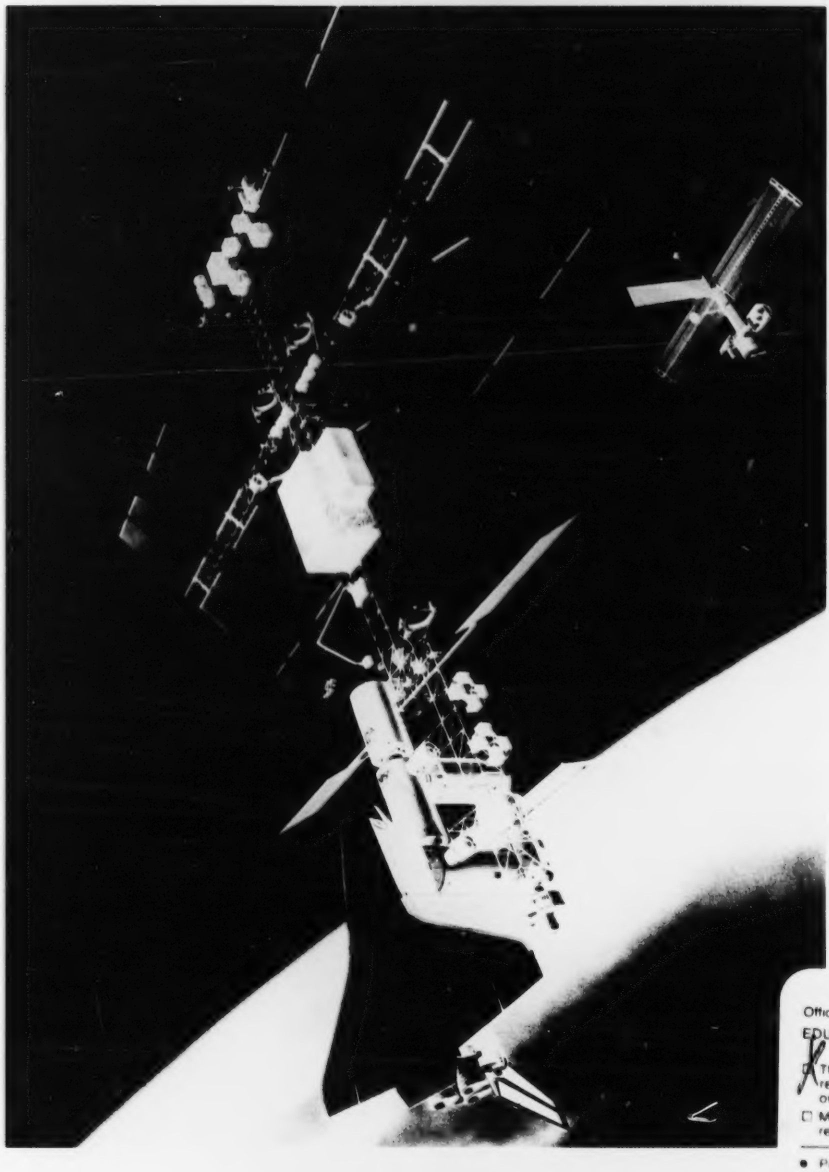

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Foreword

Future historians may describe 1985 as a year of annalistic significance, the year in which the first products made in space went on public sale—hence, the start of a new era characterized by orbital manufacture of a range of beneficial products not producible on Earth.

These initial products—reference materials used largely by research laboratories—fill essential needs but in areas so esoteric that the importance of this milestone development may not be fully appreciated by the general public. But within this decade we will see more dramatic evidence of the orbital processing potential when the first space-made pharmaceuticals become publicly available, forerunners of a spectrum of new medications for more effective treatment of serious illnesses, perhaps curatives that do not exist today.

In the decade that follows we can expect an ever-widening space product line that will make possible enormous advances in computers and other electronic systems, in communications, in superior materials for a great variety of applications and, quite possibly, consequential developments not yet predictable. The promise of orbital processing and other commercial opportunities has prompted projections that space commerce worldwide will be a half-a-trillion-dollar industry by the turn of the century.

Getting there is by no means automatic. It will take a lot of effort by both industry and government. Industry will have to make large scale investments in projects whose payoffs are years down the road. Those who accept the risks and make such commitments will have ground floor status in a field of great growth opportunity. Already a number of farsighted companies have elected to do so.

Government, for its part, must encourage and stimulate investment of private capital, and smooth the way for industry's participation in the commercial use of space. At President Reagan's direction, NASA is doing that—supporting research aimed at commercial applications, allowing easier access to government facilities, offering reduced-rate space transportation for experiments, providing technical assistance, seed money and, in some instances, an initial market.

It is vital to the national interest that U.S. industry and government join forces to realize the benefits likely to materialize from space commerce. In addition to lifesaving medications and dramatic advances in other areas of science and technology, commercial use of space is expected to generate new industries, new jobs, increased tax revenues, improvements in industrial productivity, and superior products for world markets at a time of intensifying competition in international trade. The United States has taken the lead; it is essential that we maintain it as this new phase of industrial evolution progresses.

James M Beggs

James M. Beggs
Administrator
National Aeronautics and Space Administration

Spinoff 1985

National Aeronautics and
Space Administration

Office of Commercial Programs

Technology Utilization Division

by James J. Haggerty

August 1985

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Introduction

Technology is knowledge and knowledge is readily transferable. Thus, the wealth of technology NASA has developed to meet its aerospace research goals represents an important national resource; it is a bank of technical knowledge available for reuse. It can be—and is being—applied in development of new products and processes, to the benefit of the nation's lifestyle and economy.

An estimated 30,000 secondary applications of aerospace technology have emerged in the 27 years of NASA's existence. These "spinoffs" span so broad a range of public needs and conveniences that it is difficult to find an area of everyday life they have not pervaded. Collectively, they add up to significant gain in terms of human welfare, industrial productivity and economic value, dividends on the national investment in aerospace research.

Through its Congressionally-mandated Technology Utilization Program, NASA seeks to promote broader and accelerated use of the ever-growing bank of technical knowledge. The intent is to spur expanded national benefit by facilitating the technology transfer process—making the technology readily accessible to those who might put it to advantageous use.

This publication is an instrument of that intent. Organized in three sections, *Spinoff 1985* is designed to heighten awareness of the technology available for transfer and its potential for public benefit.

Section 1 summarizes NASA's mainline programs, whose challenging objectives necessitate advances across a diverse scientific/technological spectrum and therefore expand the bank of technology that may find secondary application in future years.

Section 2, the focal point of this volume, contains a representative selection of spinoff products and processes and describes the NASA technology from which these transfers derived.

Section 3 details the mechanisms NASA employs to foster technology utilization and stimulate interest among prospective users of the technology. It also contains a brief resumé of NASA's efforts in a related field: encouraging private investment in commercial space ventures and providing assistance to companies interested in undertaking such ventures. An appendix to Section 3 lists contact sources for further information about the technology utilization and space commercialization programs.

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Assistant Administrator for Commercial Programs
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Aerospace Aims

An illustrated summary of NASA's major aeronautical and space programs, their goals and directions, and their promise of generating practical benefit to Earth's people

The Space Station, a maturing Space Transportation System and other technology advancements combine to expand opportunities for exploiting the promise of space

Space Operations

In mid-March 1985, NASA's Space Station program reached a major milestone with selection of contractors for Phase B awards, which involve definition and preliminary design of a permanently manned facility in low Earth orbit. This effort follows in the wake of extensive studies—by NASA and several contractors—concerning specific missions to be performed at the Space Station and the types of systems necessary to their accomplishment. This study-in-depth strategy is intended to reduce the likelihood of technical roadblocks in the hardware development phase, which will begin in 1987.

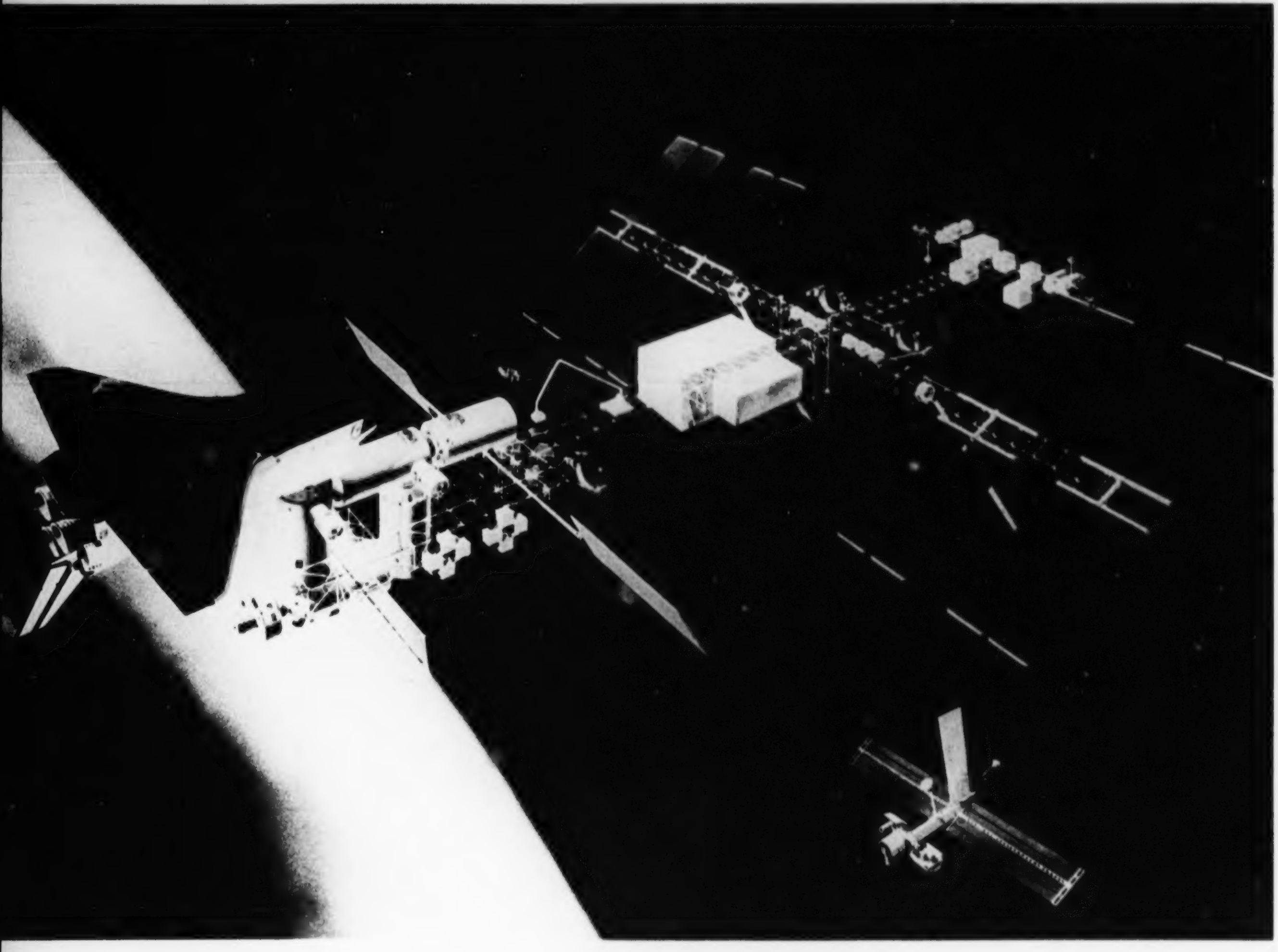
About 80 contractors, most of them veterans of the Apollo and Space Shuttle programs, will participate in Phase B. They are organized into teams, each team focusing on a "work package" in a particular area of Space Station development and each team member contributing its talents in a specific field wherein it has acquired broad expertise from prior space projects. NASA has similarly organized its field centers into teams to conduct advanced technology identification activities toward Space Station design and development. Four of the centers will oversee and coordinate contractor effort on the work packages.

In addition, NASA reached agreement with the European Space Agency, Japan and Canada whereby companies of those nations would conduct parallel Phase B studies.

Although the final Space Station design will not be determined for some time, earlier-accomplished planning studies provide a general idea of its configuration and capabilities. A NASA reference concept—called the "power tower"—envisions a 400-foot-long tower to which are affixed five pressurized modules; included are two habitat modules for a crew of six to eight, a manufacturing and technology laboratory, a life sciences module and a logistics resupply module to be exchanged on Shuttle visits every 90 days. Mounted on other parts of the tower are a large solar array to provide electricity for the station, radiators to dissipate heat and a variety of instrument systems. The orbital complex will also include two or more free-flying unmanned experiment platforms. The Space Station is being designed in modular fashion so that it can be expanded in future years, as circumstances dictate, by the addition of other modules and equipment.

The Space Station is intended to serve multiple functions. One or more modules will enable materials processing research and manufacture of many important products not producible on Earth due to adverse influences of gravity (see page 36). The station will also serve as a laboratory with a unique vantage point for advanced research in such fields as astrophysics, solar system exploration, Earth sciences and life sciences, and as a facility for developing technology in such Earth applications as communications and remote sensing. In all of these areas, man's presence will afford an extra measure of capability for observations where human skill and judgment are important, for example, in instrument selection and adjustment, in managing the data acquired by the instruments, and in overall system operation and maintenance.

Additionally, the Space Station will be an operations base, allowing continuous rather than intermittent operations in orbit, thereby increasing the amount of useful work that can be performed. It will be a checkout station for spacecraft before they are sent to their final destinations; a depot for servicing and maintaining free-flying unmanned satellites and multipayload platforms; a base for vehicles capable of delivering payloads to higher orbits and returning them when necessary

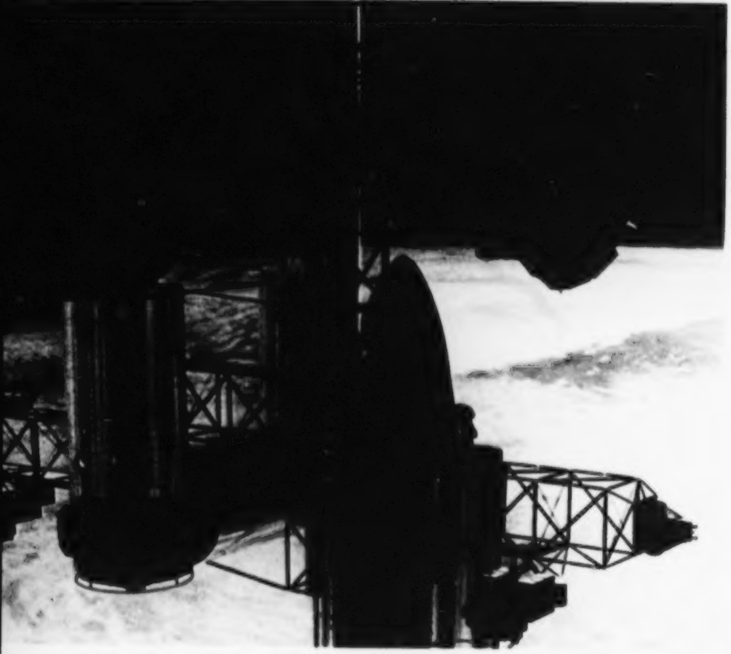


(see pages 10–11); and a construction center for erecting systems too large to be launched directly from Earth. In future years, the Space Station can become a departure point—like the base camp of a mountain climb—for such activities as building a permanent moon station, a manned mission to Mars or to the asteroids, and unmanned missions for collecting and returning to Earth samples from the distant planets.

A firm date for initial occupancy of the Space Station has not been set, but it is estimated that hardware development and deployment will take six to seven years after award—in 1987—of final design and development contracts.

Pending final design determination, this "reference configuration" offers a general idea of what NASA is planning for the Space Station of the 1990s. The concept shows a Shuttle Orbiter docked to one of five pressurized modules that provide living, working and supply facilities for six to eight people. It includes solar panels for electrical power and radiator panels to dissipate heat. About 400 feet long, the spinelike structure running the length of the station is equipped with instruments for Earth, Sun, star and galactic observations. At lower right is a co-orbiting unmanned payload platform serviced by the Space Station crew.

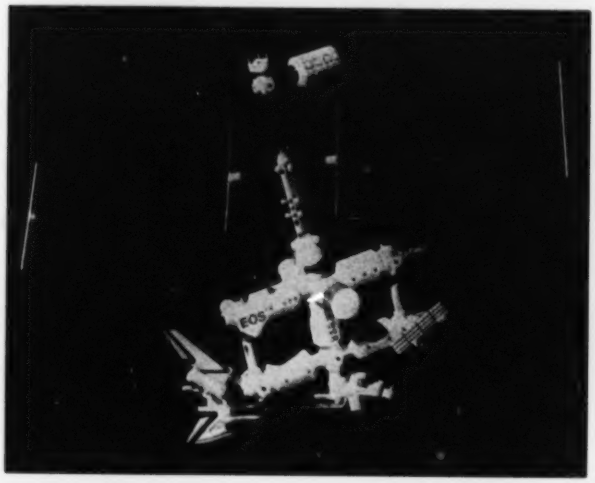
Space Station

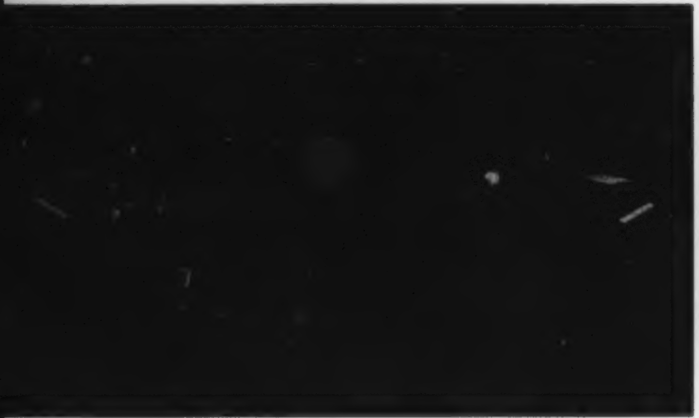


Space Station components are being designed so that they will fit into the cargo bay of the Space Shuttle Orbiter, which will deliver them to orbit. There they will be assembled by astronauts equipped with gas-powered backpack units and by a remotely operated Orbital Maneuvering Vehicle. The delivery phase will require about seven Shuttle flights. Once the station is assembled—in an orbit some 300 miles high—the Shuttle will serve as its link to Earth, providing resupply, personnel exchange and, in the event of an emergency, crew rescue.

In awarding Phase B contracts for Space Station definition and preliminary design, NASA selected competing contractor teams for each of four work packages. Work Package One is for the pressurized common modules, environmental control and propulsion systems, and accommodation for an Orbital Maneuvering Vehicle and an Orbital Transfer Vehicle (see pages 10–11). The competing teams are headed by Boeing Aerospace Company and Martin Marietta Aerospace. Marshall Space Flight Center is NASA's manager for Work Package One.

At left is a Boeing Aerospace concept of the common modules and support systems. In the center of the illustration are two vertically mounted modules; the upper is a logistics resupply module, the lower is one of two habitat modules. Below the latter, positioned horizontally, is a life sciences laboratory module. At the left side of the illustration, the vertical cylinder at bottom is a materials processing laboratory/factory; above it, mounted horizontally, is the second habitat module. Next, moving upward, is a smaller module intended for pharmaceutical processing. At top left is a hangar for an Orbital Maneuvering Vehicle; the vehicle itself is pictured at upper right, connected to a Space Station remote





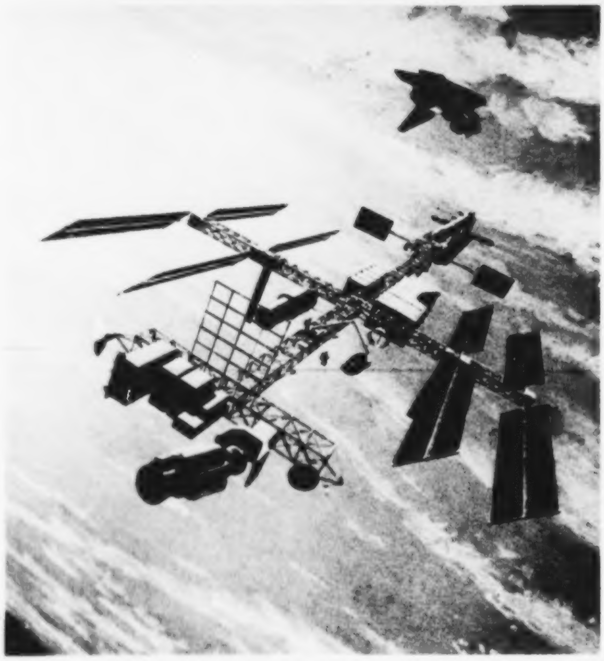
manipulator arm.

The above illustration is a Boeing concept showing one of many arrangements studied for the interior of a habitat module. It includes private quarters for each of four crew members, a galley and dining area, a command and control center, a deck for off-hours observation of Earth and space, and an airlock for access to space and to other modules: The areas above and below the living quarters house air conditioners, water processing facilities, additional equipment and storage containers. The whole module is about the size of a large mobile home.

Work Package Two, managed by Marshall Space Flight Center, is for the structural framework to which the various elements of the Space Station will be attached; interface between the Shuttle Orbiter and the Space Station; mechanisms such as the remote manipulator arm; systems for attitude control, thermal control, communications and data management; habitat module equipment; and a plan for extravehicular activity. Contractors include teams headed by McDonnell Douglas Astronautics Company and Rockwell International's Space Station Systems Division. At left below is one of a number of concepts studied by McDonnell Douglas; the illustration at upper right shows a Rockwell concept.

Work Package Three, managed by Goddard Space Flight Center, calls for design of the automated free-flying platforms and provisions for maintaining them. Contractors must also define the manner in which instruments and payloads are to be attached to the Space Station's external structure and provide a plan for equipping a module as a laboratory. The competing teams are headed by General Electric Company's Space Systems Division and RCA Astro Electronics.

Work Package Four, managed by Lewis Research Center, involves design of the electrical power generation, conditioning and storage systems. Team leaders are Rocketdyne Division of Rockwell International and TRW Inc.'s Federal Systems Division. The artwork at right, a TRW concept, shows one possible arrangement of the power tower with its solar cell panels and radiators.



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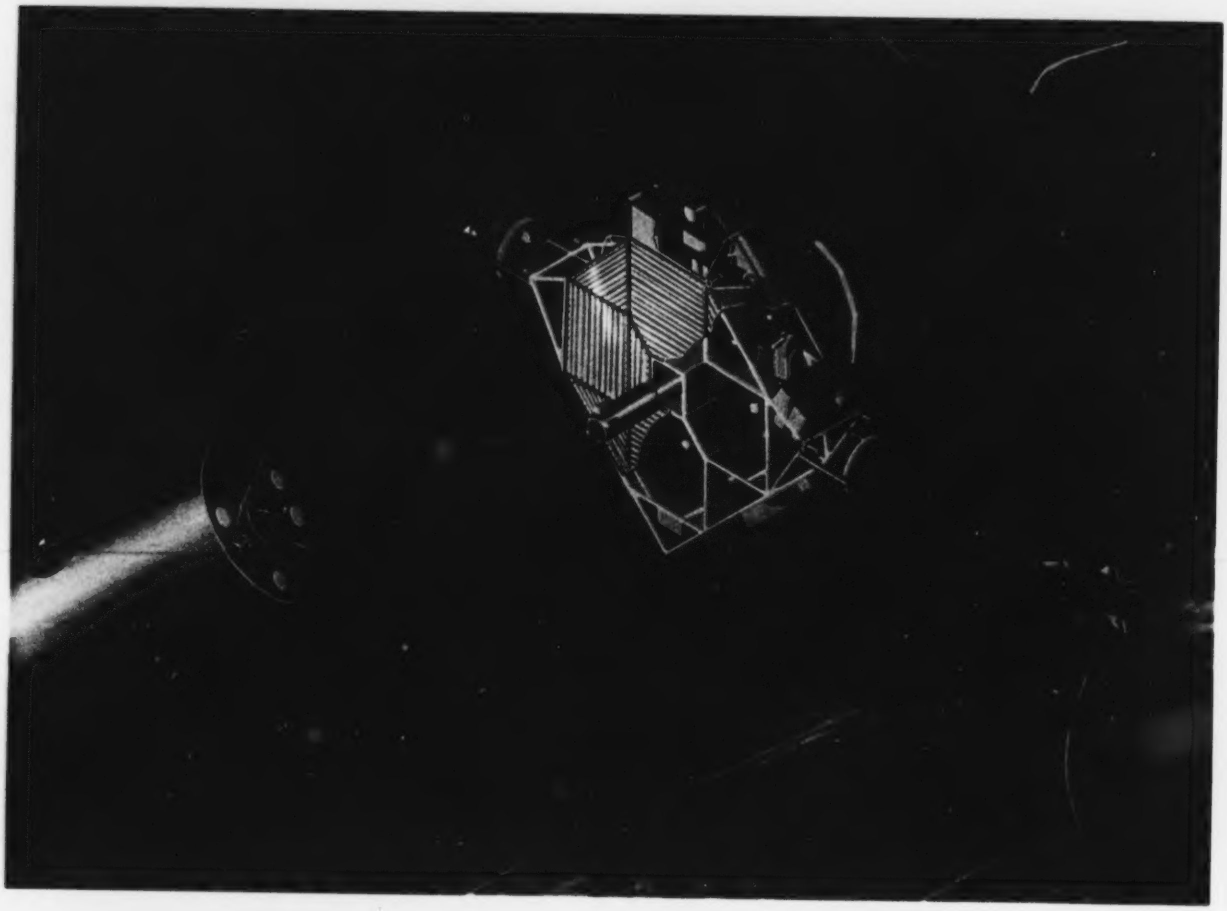
Orbital Maneuvering Vehicle

The next planned addition to the Space Transportation System is the Orbital Maneuvering Vehicle (OMV) shown in the accompanying artist's concept. The OMV is described as a "smart space tug" capable of moving satellites and other objects in space from one orbit to another. It is intended for use initially with the Space Shuttle, later with the Space Station, its operation human-controlled—with the help of television and other sensors—by Shuttle-based or Space Station-based astronauts. The basic concept developed by Marshall Space Flight Center envisions a remotely piloted unmanned vehicle about 15 feet in diameter and three feet long.

Last year NASA awarded OMV system definition study contracts to three companies: LTV Aerospace and Defense Company, Martin Marietta Denver Aerospace and TRW Inc. After evaluation of those studies this year, NASA plans to select a company to build the flight hardware. The OMV is targeted for first use about 1990.

As a supplement to the Space Shuttle, which normally operates at altitudes from 150 to 300 miles, the OMV will extend the Shuttle's reach to an altitude of more than 1,000 miles. It will be used to deliver payloads to orbits not attainable by the Suttle, to retrieve satellites from high orbits for Shuttle-based maintenance and repair, and to place repaired satellites back in their operational orbits. Additionally, it will provide a means of reboosting satellites whose orbits are decaying.

The OMV is intended to play a key role in assembly of the Space Station, maneuvering into position the various modules and segments of the station delivered to orbit by the Shuttle. When the Space Station becomes operational, the OMV will become a station-based work vehicle for such tasks as satellite deployment and retrieval, positioning Shuttle-delivered resupply modules, or adding new modules.

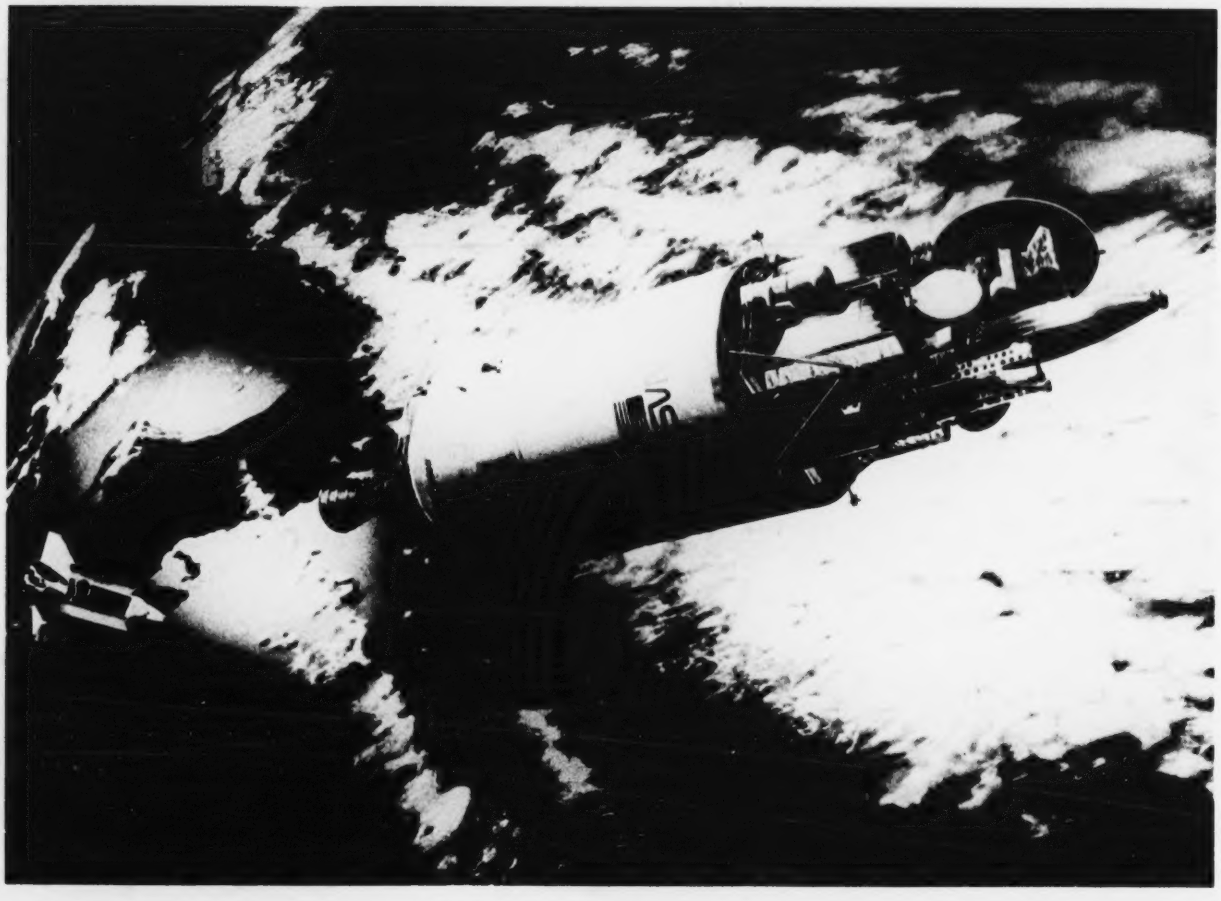


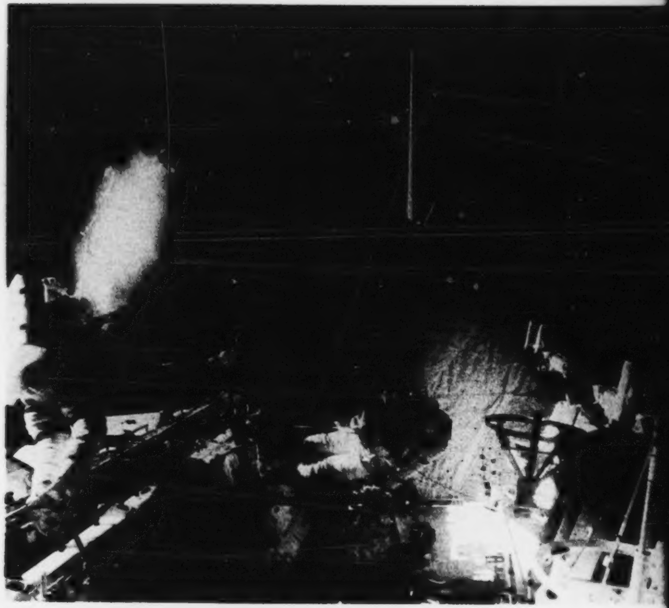
Orbital Transfer Vehicle

Looking to future years of the Space Station era, NASA is seeking to develop a capability for improved access to geosynchronous orbit (GEO), an orbit 22,300 miles high where spacecraft are figuratively stationary with respect to a point on Earth. Sending spacecraft to GEO—commercial communications satellites, for example—is now a two-stage process in which the payload is deployed from the Space Shuttle in low Earth orbit, then boosted by an upper stage propulsion unit. Existing upper stages are not reusable, nor can they retrieve satellites from GEO.

To meet the need for a GEO-access spacecraft, Marshall Space Flight Center (MSFC) is studying an advanced upper stage known as the Orbital Transfer Vehicle (OTV). Targeted for operational service in the 1990s, the OTV would be a reusable system that would add a new dimension of space capability by ferrying payloads from one orbit to another up to—and down from—GEO altitude. The OTV may be permanently based at the Space Station or it may operate as an adjunct to the Space Shuttle; MSFC is studying both options.

Initially the OTV would be an unmanned vehicle capable of retrieving satellites from GEO and bringing them to the Space Station for repair and servicing, or to the Shuttle Orbiter for return to Earth and refurbishment. The ultimate goal is development of an OTV that could ferry a manned capsule to GEO, allowing on-orbit servicing of spacecraft or multipayload platforms.





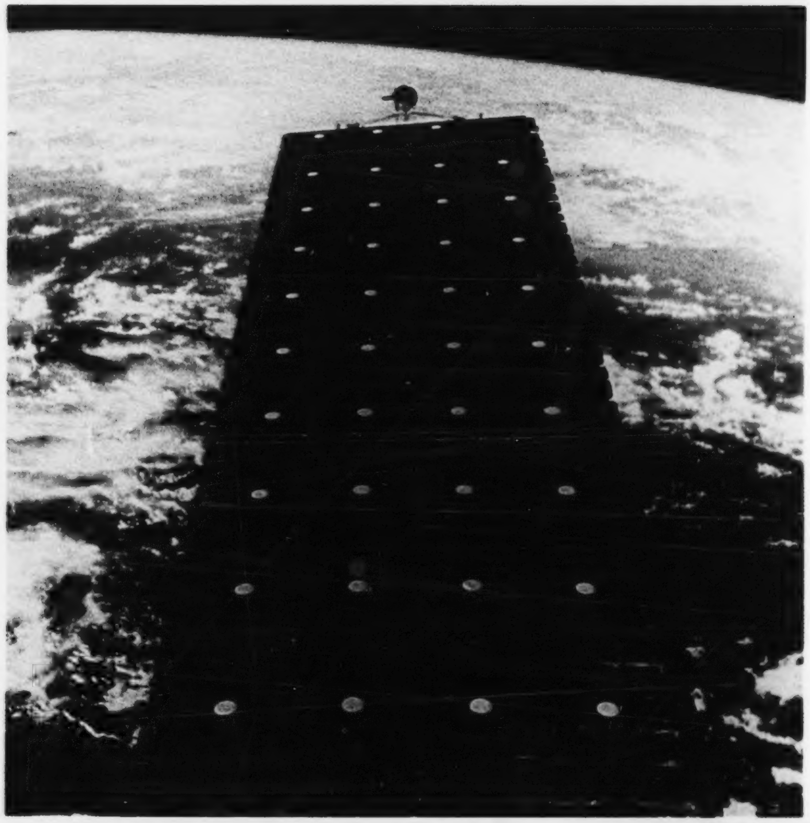
Shuttle Operations

In May 1985, the National Aeronautic Association presented the aerospace community's highest award—the Collier Trophy—to a NASA/astronaut/industry team for the greatest achievement in aeronautics/astronautics during 1984. The achievement was the dramatic advancement in space capability exemplified by the introduction of the Manned Maneuvering Unit (MMU) and its subsequent use on two satellite retrieval missions flown by the Space Shuttle.

The MMU, a backpack propulsion unit that enables astronauts to operate independently of the Space Shuttle, was first demonstrated on a February 1984 Shuttle flight. Astronauts Bruce McCandless and Robert L. Stewart became the first "human satellites," flying as far as 300 feet from the Shuttle Orbiter. In April 1984, astronaut George Nelson flew the MMU to a rendezvous with the malfunctioning Solar Maximum Observatory to stabilize it for recovery by the Orbiter. After the crew replaced the faulty module with a new one, Solar Max was redeployed in orbit to continue its scientifically important observations of solar phenomena. This marked history's first recapture and redeployment of an orbiting spacecraft.

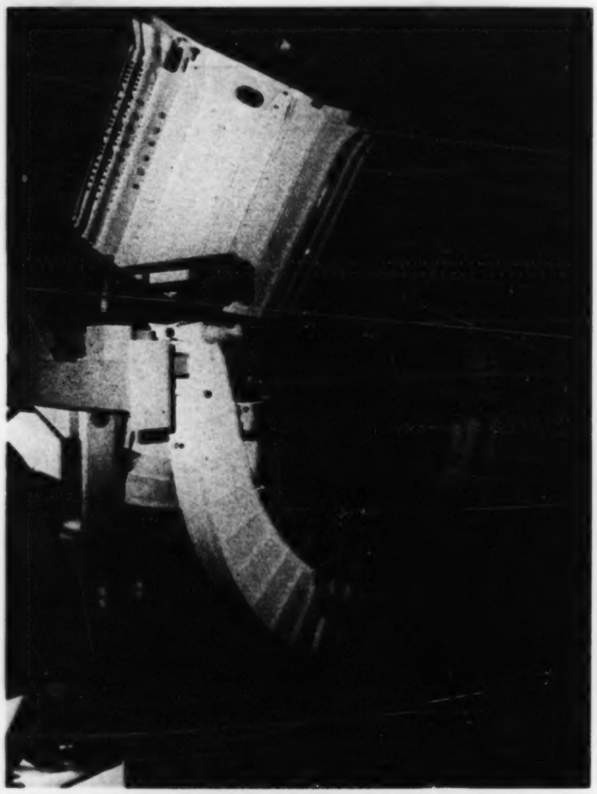
In November 1984, a Shuttle crew further demonstrated the new capability by effecting the retrieval of two commercial communications satellites that had been sent into improper orbits earlier in the year. At upper left astronaut Dale A. Gardner is docking with the Westar 6 satellite; he used his MMU to maneuver it to the Shuttle Orbiter for retrieval. Above, astronaut Joseph P. Allen and Gardner are wrestling the previously stranded Palapa B2 satellite into the Orbiter's cargo bay. Palapa and the Westar-6 satellite were returned to Earth for refurbishment and future reuse.

Another advancing capability was demonstrated on an August 1984 Shuttle mission, which featured the first space test of a 102-foot-long, lightweight, foldable solar array capable of being restowed after deployment in space (above right). This experiment, designated OAST-1, was directed toward future need for larger solar arrays that cost less, are larger yet lighter, can be stored more compactly for transportation to orbit and, most importantly, can be retracted and restowed for servicing and reuse. The OAST-1 solar array is a forerunner of "wings" designed to cost about half as much as existing rigid solar arrays, weigh about one-eighth as much and fold up into a package only seven inches thick; it is composed of very thin solar cells mounted on a plastic "blanket" instead of the conventional aluminum support frame. During the flight, the Orbiter crew successfully extended and retracted the array several times and acquired extensive data on the structural dynamics of



the system. King-size flexible lightweight solar arrays of this type offer utility as power sources for extended duration Shuttle missions, for the Space Station and for large unmanned orbiting platforms. Marshall Space Flight Center is manager of the OAST-1 project; the system was built by Lockheed Missiles & Space Company.

A highlight of the 15th Shuttle flight in January 1985 was the return to service of the Inertial Upper Stage (IUS) after a 15-month hiatus during which problems discovered on an earlier flight were corrected. The Shuttle flight was a classified Department of Defense mission and no details were announced, other than the fact that the IUS had performed successfully. At right, the IUS is shown in a ground facility undergoing checkout in a replica of the Orbiter cargo bay support fixture from which it is deployed. Developed by Boeing Aerospace Company under Air Force contract, the IUS is used by both NASA and the Department of Defense.



Student Experiments

Pictured below with their teachers/advisors are the 1984 winners of the Shuttle Student Involvement Program, a nationwide competition in which secondary school students propose scientific experiments for possible flight aboard the Space Shuttle. Jointly sponsored by NASA and the National Science Teachers Association, the program is intended to stimulate interest in science and engineering among the nation's youth. From several thousand entries, up to 10 winning proposals are selected each year, primarily on the basis of scientific/engineering merit and originality. Each student winner is paired with a corporate sponsor and a NASA scientist or engineer, who work with the student to determine the feasibility of developing the proposal into an actual flight experiment. Sponsors and advisors later help the student analyze the data from his experiment.

An example of a winning project, flown aboard a 1984 Shuttle mission, is one designed by Shawn P. Murphy, then of Newbury (Ohio) High School, now at Hiram College in Ohio. Murphy's experiment involved test of a "floating zone" technique for growing a large single crystal in zero gravity. In this technique, the sample material floats within, but not in contact with, an annular heater; the sample is melted, then—when the heat source is withdrawn—allowed to solidify into a crystal of theoretically superior purity and quality. The technique has potential application in production of advanced semiconductor materials.

Rockwell International sponsored Murphy's project and made available its Fluids Experiment Apparatus (FEA), a small zero-gravity chemistry/physics laboratory designed for Shuttleborne commercial materials processing experiments. The student project marked the first use of the FEA aboard the Shuttle.

Another example is a proposal by Andrew I. Fras of Binghamton (New York) High School. Fras' experiment, to be flown aboard the Shuttle this year, involves sending 100 young flies into space to determine whether weightlessness accelerates the aging processes of organisms. In post-flight analysis, the space flies will be compared with 100 other flies of the same age kept on Earth in conditions identical to those of the flies carried into space. Fras' proposal was one of the 10 winners selected in 1984 from some 3,000 entries; he became the first student to win the competition twice since its inception in 1982. His flies-in-orbit experiment was sponsored by the Los Angeles (California) Orthopaedic Hospital.

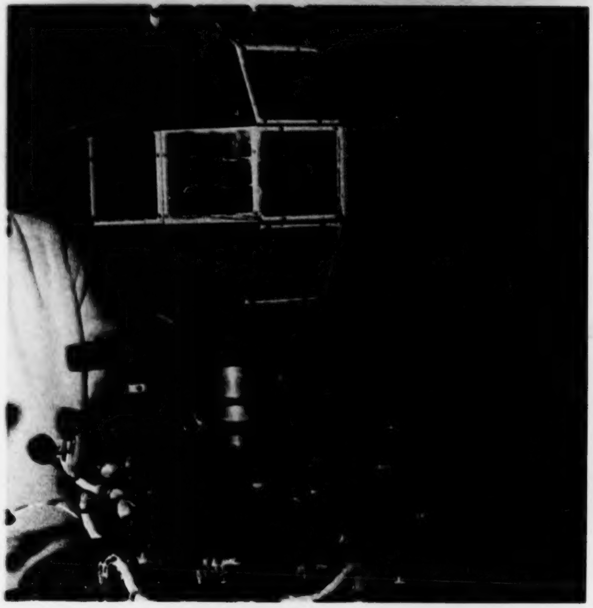
Getaway Specials

On some Space Shuttle flights, there is leftover room in the Orbiter's cargo bay after primary payloads have been accommodated. NASA is taking advantage of this space availability to allow low-cost use by experimenters who could not justify or could not afford the expense of a primary payload—individuals, small companies, educational institutions or research organizations. Under the "Getaway Special" program, researchers can put aboard the Orbiter small payloads of their own design, housed in NASA-supplied cylindrical canisters; the canisters range in volume from two and a half to five cubic feet and in weight from 60 to 200 pounds. The aim of the program, which is managed by Goddard Space Flight Center, is to stimulate broader interest in space research among the large segment of the scientific community not engaged in development of primary payloads.

Payloads must be of a scientific or industrial research nature. Normally they require no special activation or tending by the Shuttle crew; they are exposed to the space environment in the open cargo bay of the Orbiter, then returned to Earth for analysis.

In 1985, NASA is introducing a new aspect of the program in which small satellites are spring-ejected from Getaway Special canisters into independent orbit. One such is a satellite for calibration of ground-based air traffic control radars; called NUSAT, for Northern Utah Satellite, it is designed to measure antenna patterns of radars operated by the U.S. Federal Aviation Administration. The 19-inch-diameter NUSAT (right above) was developed and built by a university/industry/government team, headed by Weber State College, Ogden, Utah, in coordination with the FAA. The satellite retention/ejection system was developed jointly by the project team and Goddard Space Flight Center, based upon a McDonnell Douglas Corporation design.

Another canister-ejected satellite is GLOMR (Global Low Orbiting Message Relay), a 150-pound data relay communications satellite designed and built by Defense Systems, Inc., supported by NASA and the Defense Advanced Research Projects Agency. Powered by solar cells, GLOMR (right) is expected to operate in orbit for about one year. For these and other small ejectable satellites, Goddard developed a special canister with a motorized opening lid.



NASA aeronautical research is providing new technology for coming generations of better performing, more efficient aircraft

Toward Future Flight

an airplane stall occurs when the plane loses lift due to disturbance of the smooth airflow over and under its wing; the stall can cause the airplane to depart from controlled flight and go into a spin. Stalls and the resulting spins are usually caused by flying too slowly to sustain lift or by flying at an angle of attack—the angle between the wing and the air striking it—so high that the airflow separates from the wing. In modern lightplanes, the stall by itself is not dangerous if the pilot has sufficient altitude to make a recovery. But spin-causing stalls sometimes happen during improper takeoff, landing or low speed maneuvers—and when they do they can cause a fatal accident.

NASA research has provided a means of reducing the number of fatal lightplane accidents by lessening the threat of spin. NASA's remedy is a simple reshaping of part of a lightplane wing, the product of several years of research effort by Langley Research Center and Ames Research Center. The modification has been proved effective in wind tunnel trials and in flight tests of three types of lightplanes.

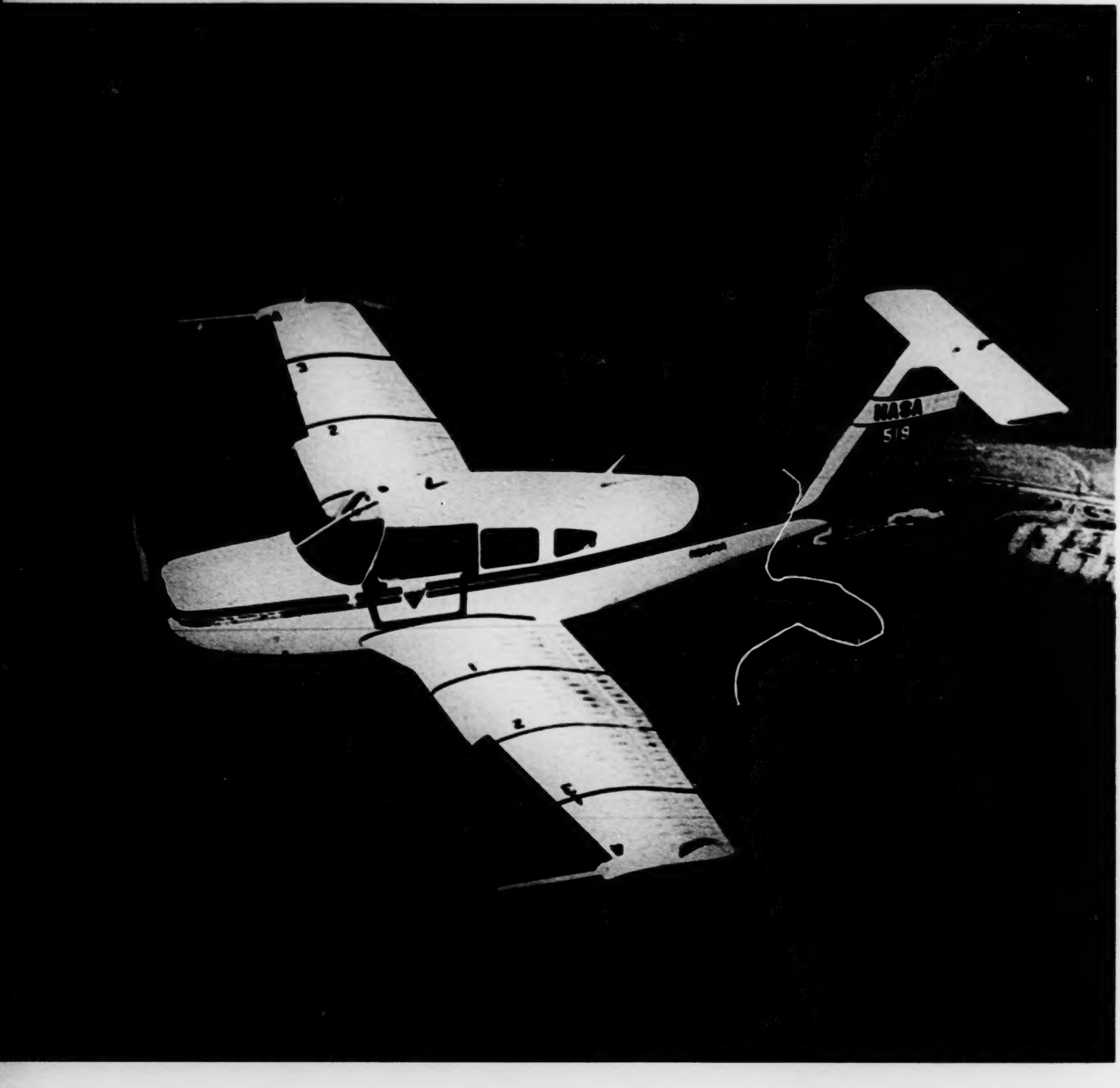
Called the "discontinuous wing," the modification is a carefully designed "glove" mounted on the outer portion of the wing's leading edge; it covers the first six inches of the upper surface and the first 18 inches of the lower surface. The glove is light, has no moving parts and requires no maintenance. It does cause a slight increase in drag, but in NASA tests the performance penalty amounted to a negligible loss of cruise speed—one to two miles per hour.

At the glove juncture, there is an abrupt transition between the original leading edge and the recontoured area. The glove extends about two inches forward of the original wing and the extended leading edge area is drooped and more rounded than usual. At high angles of attack, the abrupt transition of wing shape generates a whirlpool-like airflow called a vortex. The vortex acts like a wall to bar passage of stalled, or separated air; in other words, it keeps the separated air inboard so that it does not disrupt the smooth airflow on the outer part of the wing. The drooped leading edge tends to keep the flow "attached" longer to the wingtip area.

Langley research pilots pressed the three modified lightplanes to angles of attack almost twice as high as normal before encountering any spin tendency. Before they were gloved, the three planes would begin to spin about 18 of 20 times when the wings were deliberately stalled. After modification, the same planes entered a spin only once in every 20 attempts. The pilot generally had three to four times as long—measured in seconds—to make a correction before the plane started to spin.

The research is being expanded beyond the initial series of unswept, low-wing airplanes to include high-wing aircraft and others with different airfoil shapes. In addition, further wind tunnel work is being conducted for NASA at the University of Maryland, College Park, Maryland. In that effort, university researchers are using visual airflow techniques to define the exact flow mechanisms that make the gloved wing so much more spin resistant. NASA's ultimate goal is to give airplane designers the ability to incorporate the modification as an integral part of a new wing design, rather than an add-on. NASA also plans to provide designers the analytical tools to determine the amount of spin resistance needed for new airplanes, thus generalizing the solution for all conventional lightplanes.

The wing modification work exemplifies one area of NASA's comprehensive aeronautical research program: generating technology for solution of current and predictable aviation problems. Other examples include curbing jetliner fuel consumption, reducing



This Piper PA-28 Arrow looks like the standard version, but it incorporates an important safety modification. "Gloves" outboard on the wing (red areas) change the contour, making the wing leading edge drooped and more rounded than normal. This simple reshaping of the wing markedly reduces accident-causing stalls and spins.

aircraft and helicopter noise, finding ways to alleviate airport congestion and a variety of safety-related investigations, such as research on fire resistant materials and improved aircraft structures for better passenger protection.

The main thrust of NASA's aeronautical research is directed toward anticipating the longer range needs of future flight and developing applicable technology. Part of this effort involves research of a general nature aimed at advancing aerodynamics, propulsion, materials and structures, aviation electronics and knowledge of the human factors in flight operations. The other part embraces technology development for improving the performance, efficiency and environmental acceptability of specific types of flight vehicles, such as tomorrow's general aviation planes, rotary wing aircraft, advanced jetliners and high performance military aircraft.

Agricultural Spraying

Since 1976, NASA has been conducting research related to aerial crop dusting and spraying, an effort designed to help the aerial application industry solve a major problem: chemical drift. Wasteful drift of chemicals beyond target areas was becoming more expensive as chemical costs increased; additionally, drift was heightening environmental concerns. Langley Research Center has devoted almost a decade of effort to minimizing drift losses, focusing on determining the characteristics of aircraft wake and how the wake affects chemical dispersal patterns. Langley's aim was to integrate wake characteristics with dispersal equipment to produce wider, more uniform application patterns for liquid or solid chemicals.

From this effort has come an important advance: a computer code—made available to aerial applicators and equipment designers—which represents the first spray prediction technique that incorporates both atmospheric and aircraft aerodynamic properties and thus offers greatly improved accuracy. Developed by Langley under funding provided by NASA and the Department of Agriculture's Forest Service, the code is called AGDISP (for AGricultural DISPersal). It takes into account the effects on particle trajectories of atmospheric turbulence, crosswind, propeller slipstream, terrain variations, droplet evaporation and plant canopy density.

The code allows operators to evaluate the influence of flight conditions—such as airspeed or altitude—on ground deposit patterns; it helps them determine the best flight procedures for a given set of atmospheric conditions and to decide whether to spray under existing conditions. For designers of aircraft and dispersal equipment, the code serves as a means of predicting how modifications to the airplane or dispersal system can improve ground deposit patterns; it permits analysis of aircraft configurations and dispersal equipment without costly flight tests for each aircraft and nozzle system. Although complex in principle, the code is easy to use; one software company is making it available in a language compatible with home computers.

Langley wind tunnel tests of models and a full-scale airplane showed that it was possible to alter aircraft wake and measure the resulting impact on spray patterns. Experimental flights were conducted at NASA's Wallops Flight Facility with an Ayres Thrush agricultural plane loaned without charge by Ayres Corporation, Albany, Georgia. The tests provided wake interaction data showing the influence of atmospheric and airplane operating conditions on applications. Comparison of AGDISP predictions with flight test data showed generally good agreement.

AGDISP also correctly predicted that use of winglets, vertical extensions of the wing at either tip, would improve application results. Winglets—an earlier-developed NASA technology for improving the cruise performance of aircraft—were added to the test plane as a means of combating the effects of the "wake vortex," an air whirlpool that occurs at an airplane's wingtip and exerts a powerful influence on the airflow behind the airplane. The vortex is illustrated in the accompanying photo; the normally invisible vortex was made visible by a technique that employs colored smoke rising from the ground. The effect of the winglet modification was to move the vortex higher—farther from the spray nozzles—so that fewer particles were entrained by the vortex, hence there was considerably less particle drift.

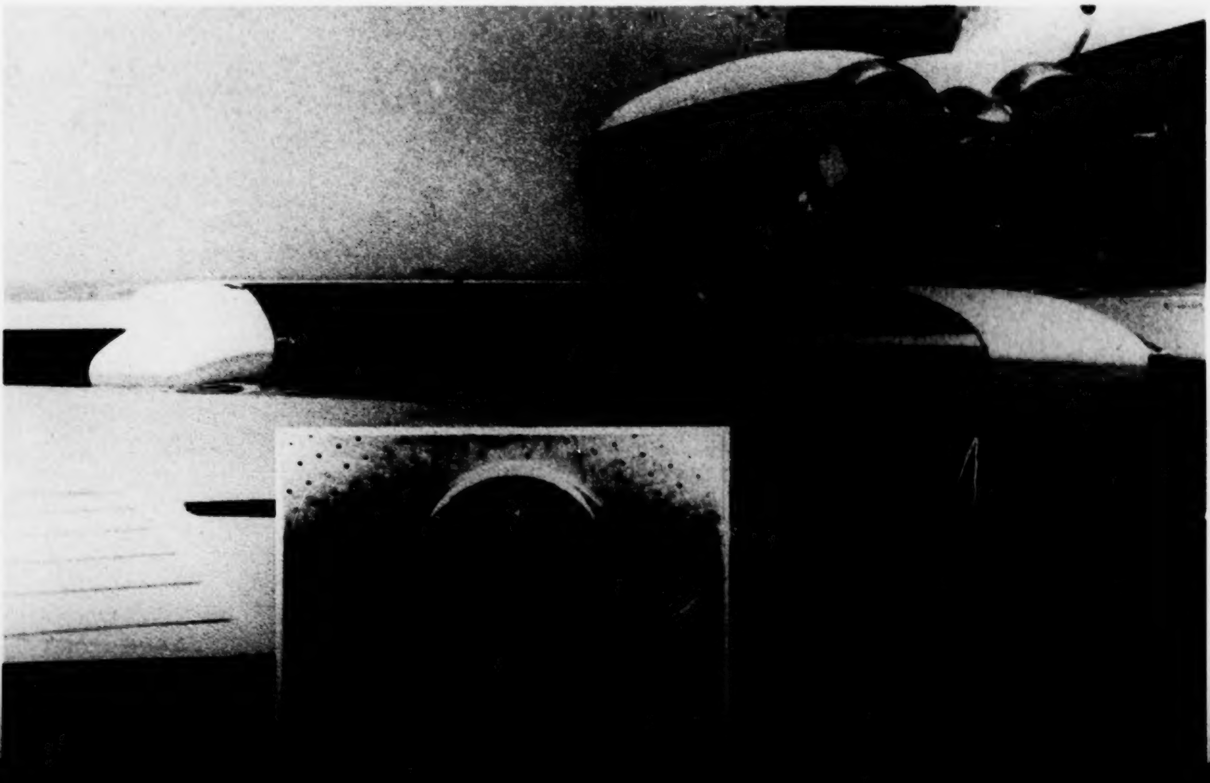
Airflow Control

Last summer, as part of its Aircraft Energy Efficiency Program, NASA began flight tests of two advanced technology wing panels, precursors of a system that could provide fuel savings of as much as 25 percent for future airliners. The panels are mounted on the wing leading edge of a NASA C-140 JetStar (below), one on either side of the fuselage. They are components of a Laminar Flow Control (LFC) system that employs suction to maintain a smooth, or laminar, flow of air over the wing.

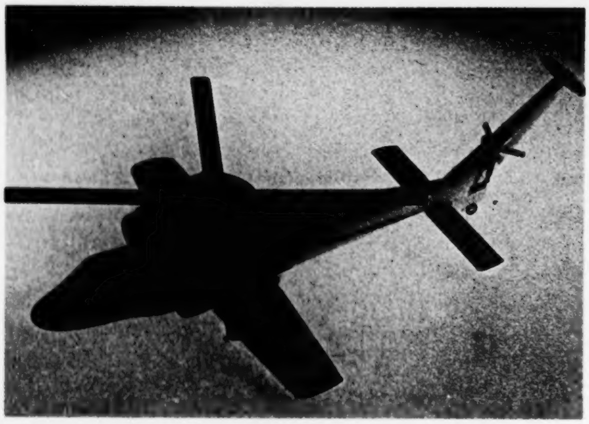
LFC is a means of controlling the "boundary layer," the layer of air next to an airplane's skin. At low speed, the boundary layer is normally smooth but as speed increases it becomes turbulent, creating aerodynamic drag; at jetliner cruise speeds, this drag—caused by friction between the turbulent air and the airplane skin—amounts to roughly half the airplane's total drag. The LFC system employs suction pumps to remove the turbulent air by drawing it into the wing through microscopic holes or slots, thus maintaining smooth airflow throughout a flight. McDonnell Douglas Corporation, which developed one of the two wing panels being tested, estimates that an effective LFC system on its DC-10 jetliner could save up to $2.2 million in fuel costs during a typical service year.

The bottom photo illustrates the McDonnell Douglas/NASA wing panel concept used on the right wing of the C-140 test plane; the panel, six feet long, is the dark segment of the wing's leading edge. Made of a thin sheet of strong, corrosion resistant titanium, the panel appears to be solid but actually it is perforated by more than a million tiny holes, shown magnified in the inset; the object in the inset is a paper clip, intended as a comparison reference to show the size and spacing of the holes. There are 800 holes to each square inch of panel surface; drilled by an electron beam, the individual hole is diametrically less than the size of a human hair.

A companion panel, located on the left wing, was developed by Lockheed-Georgia Company. Instead of holes, it contains 27 spanwise slots, each measuring only three thousandths of an inch in height. Similar in operating principle, both systems include methods of dispensing a solvent onto the wing leading edge to dispose of insects and ice that could block the suction holes or slots. Both performed well in initial tests, conducted by Dryden Flight Research Center. Beginning this year, Dryden will use the C-140 for 12 months of advanced LFC testing, flying simulated airline operations—at customary altitudes in atmospheric conditions prevalent in various parts of the country—to evaluate the two concepts in a realistic flight environment.



Rotary Wing Research



The aircraft at upper right is one of two Rotor Systems Research Aircraft (RSRA) built by Sikorsky Aircraft for a NASA/Army investigation of promising rotorcraft concepts with future commercial or military potential. In this configuration, the RSRA is flying without its main rotor, its lift generated by a fixed wing and power supplied by two General Electric turbofan engines. From May through September last year, the RSRA made 13 rotorless flights, reaching speeds of 300 miles per hour and altitudes up to 10,000 feet.

The reason for this series of tests was to demonstrate the fixed wing capability of the hybrid helicopter/airplane and explore its flight envelope and flying qualities in preparation for a new "X-wing" research program sponsored by NASA and the Defense Advanced Research Projects Agency (DARPA).

One of the two RSRAs is being modified to incorporate a four-bladed, extremely stiff rotor that can be stopped in flight. For takeoff, hovering and low speed flight, the rotor functions as a helicopter rotary wing. At a speed of about 200 miles per hour, the rotor is stopped and locked in place to become, in effect, two forward-swept wings and two aft-swept wings in an "X" configuration (right). In the latter mode, it is

expected that the concept will have a speed potential approaching 500 miles per hour. The X-wing aircraft offers utility as a short-haul transport for civil or military service beginning about the end of the century. The project is managed by Ames Research Center, which will conduct flight tests in the X-wing configuration starting this year.

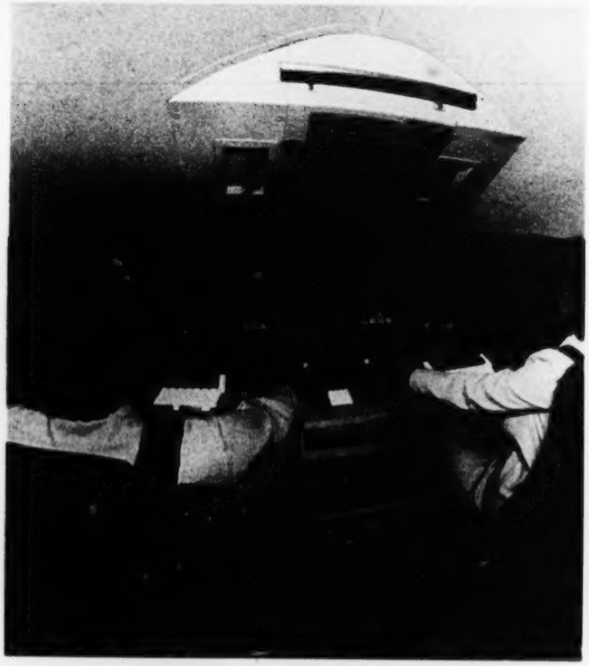
Another candidate for tomorrow's short-haul air transportation system is the tilt rotor aircraft which, like the X-wing, combines the vertical lift advantages of the helicopter with the greater forward speed of the fixed wing airplane. The feasiblity of this concept has been demonstrated in six years of flight tests—conducted by Ames Research Center—of the XV-15 Tilt Rotor Research Aircraft. The program is a joint NASA/Army effort; Bell Helicopter Textron built the two experimental vehicles.

The XV-15 has helicopter-like rotors for vertical takeoff, hovering and landing (opposite page, bottom); for cruise flight, its rotors tilt forward to become propellers (left) that drive the craft at speeds up to 350 miles per hour. Successful NASA/Army testing led to a Department of Defense design and development program for an advanced tilt rotor aircraft based on the XV-15 and known as the V-22 Joint Services Vertical Lift Aircraft. Bell Helicopter Textron and Boeing Vertol Company have teamed for development of the military version and both companies are exploring the civil potential of the tilt rotor concept. Ames continues to test the XV-15 to provide an expanded data base in support of the military V-22 program and as a means of investigating advanced concepts for future civil commuter aircraft.

A new rotary wing program started in 1984 involves development and test of a very large helicopter designed to lift a 35-ton payload, about double the weight that can be lifted by the largest currently operational U.S. helicopter. Known as the Heavy Lift Research Vehicle (HLRV), the aircraft will be used in an Army/NASA/DARPA ground and flight test program to demonstrate critical heavy lift technologies and to establish a data base to reduce the risk in future large helicopter developments. The program is a revival of a heavy lift helicopter development initiated by the Army in the early 1970s and later suspended; the primary structure (below) and other components completed before the suspension were kept in storage and will be used in the new program. Boeing Vertol, the original Army contractor, will complete construction of the HLRV and instrument it for the special requirements of the advanced research program. First fights are planned for 1988.

Human Factors Research

Studies indicate that human error plays a part in 60 to 80 percent of all aviation accidents. Until now, there has been no practical way to study *how* errors are made and how increasing automation—in the cockpit and at air traffic control stations on the ground—affect human performance. A new NASA facility at Ames Research Center makes such studies possible; called the Man-Vehicle Systems Research Facility (MVSRF), it became operational last year.



MVSRF is a simulation complex intended to improve air transportation safety through studies of the relationships among aircraft crew members, the airplanes they fly and the air traffic environment in which they operate. Such studies—called human factors research—are aimed at greater understanding of aircrew capabilities and limitations. The goals of such research are improved flight deck instrumentation and solutions to human-related problems affecting aviation safety and efficiency.

The facility houses two advanced flight deck simulators that can be operated independently or interactively as two aircraft flying in proximity. It also includes an Air Traffic Control Simulator that provides a computerized representation of the air traffic environment; it is capable of simulating large numbers of aircraft in a given airspace flying on different headings at different speeds and altitudes. These simulators enable scientists at observer stations to monitor "flights" by aircrews under realistic conditions—crowded approach and landing patterns, interchange with air traffic controllers and operation in clear or bad weather. The observers can introduce problems, such as turbulence, fog, uncoordinated traffic and mechanical failures. Thus, scientists can study how human reactions and decisions are affected by cockpit instrument displays, ground-based air traffic control information, environmental conditions and hardware malfunctions.

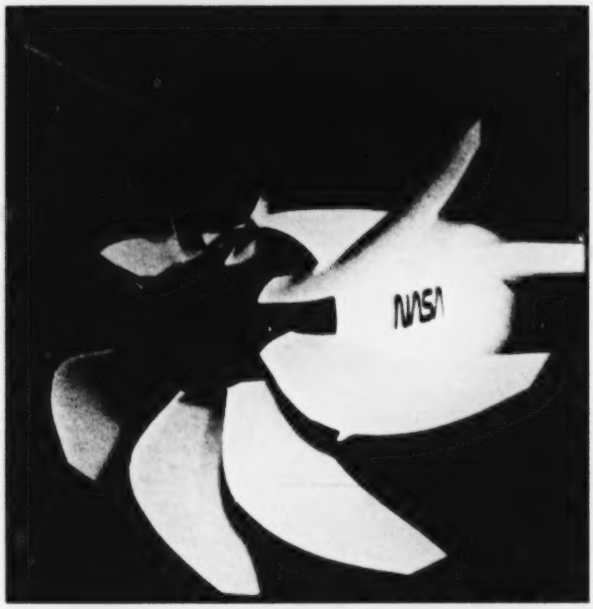
The two flight deck simulators represent the cabs of commercial transport aircraft. One (upper left) replicates the cab of a current technology jetliner, the Boeing 727; it was developed by Ames Research Center in cooperation with Link Division of The Singer Company, Binghamton, New York. The other, a cooperative project of Ames and Lockheed-Georgia Company, Marietta, Georgia, is called the Advanced Concepts Flight Simulator (left); it has flight controls and displays representative of a commercial transport that might be in service a decade hence. Both simulators have visual window displays that depict other aircraft in the vicinity and accurate views of many major U.S. airports as they would appear in dusk, night, fog, cloud, or other weather conditions. Realism is further enhanced by an auditory system that creates the sounds of aerodynamic effects, engine operation, landing gear extension and runway touchdown noises.

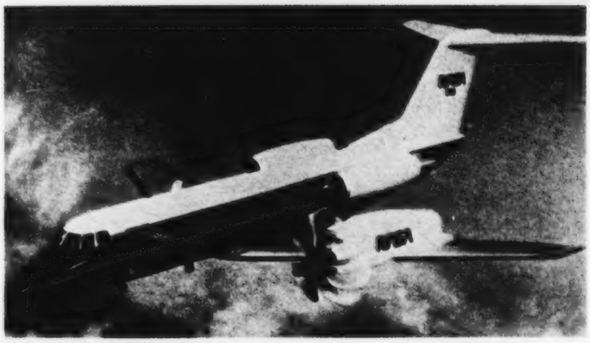
Advanced Turboprop

Although jetliner fuel costs have moderated in recent years, they are still several times what they were before the oil crises of the 1970s. Today, fuel accounts for some 30 percent of an airline's total operating costs and future prices are uncertain. That's why there is a revival of interest in the turbine/propeller engine, or turboprop. The turboprop offers inherently better fuel consumption than the jet engine; its drawback is that propeller tip speed limitations hold down airplane speed. If that drawback can be eliminated, allowing turboprop-powered aircraft to fly at jetliner speeds, the propeller may stage a comeback in commercial service and allow airline fuel savings of billions of dollars annually.

For several years, Lewis Research Center has been working toward that end, developing technology for "propfan" systems that could be available to aircraft manufacturers in the early 1990s. Propfan designs feature extremely thin blades that sweep back away from the direction of rotation to provide greater efficiency at high tip speeds. The blades are also shorter than those of conventional propellers, so the tips do not have to move as fast for a given speed requirement. To compensate for the thrust reduction caused by shortening the blades, the propfan has more blades—typically eight. Wind tunnel tests have shown that propfans driven by advanced engines could power commercial transports to speeds comparable with those of existing subsonic jetliners at fuel savings on the order of 30 to 40 percent.

Extensive design work has been completed and testing is under way on a multiblade nine-foot diameter propfan assembly developed for Lewis by Hamilton Standard Division of United Technologies. Last year, General Motors' Allison Gas Turbine Division was awarded a contract for modification of an existing engine and gear box to drive the propfan. The whole test assembly (top right)—propfan, gear box, engine and a new-design engine nacelle—will be mounted on a light transport airplane (middle right) being modified by Lockheed-Georgia Company under contract to NASA. Beginning in 1987, after a full range of ground tests, Lockheed will flight test the system to explore its structural and acoustic characteristics. Meanwhile, Lewis will conduct ground tests of a different type of propfan, General Electric Company's "unducted fan" (right), which has no gear box and two rows of eight propeller blades, each row rotating in a direction opposite to the other.



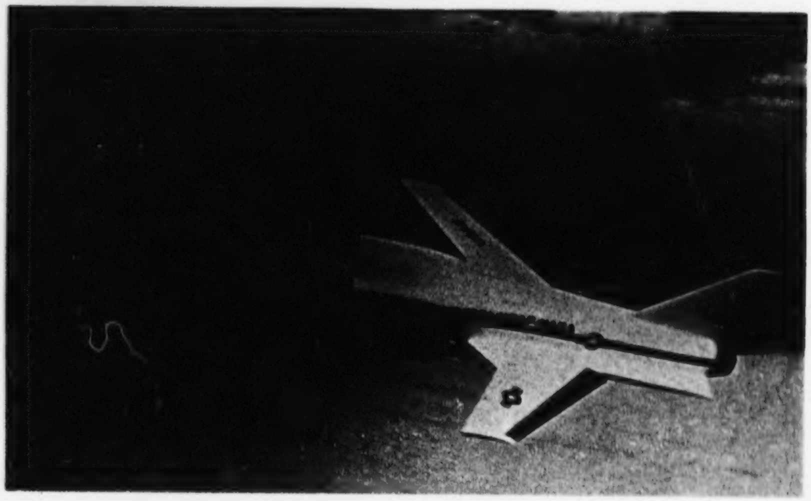


High Performance Aircraft

Shown on its first flight in December 1984 (left) is the Grumman-built X-29A technology demonstrator, which features a unique forward-swept wing and a number of other advanced technologies. Principal sponsor of the program is the Defense Advanced Research Projects Agency, which is supported by the Air Force and NASA. Langley Research Center and Ames Research Center continue to conduct wind tunnel tests and Ames-Dryden Flight Research Facility is handling the 18-month government flight test program, which began in April.

A unique research airplane rather than a prototype of a combat aircraft, the X-29A represents a major departure from traditional fighter aircraft design. The major technological advance to be validated by the flight test program is the forward-swept, thin supercritical wing (below), which is made of composite materials; at transonic speeds, the wing offers a drag reduction of as much as 20 percent in comparison with the conventional aft-swept metal wing. The combination of the advanced geometry composite wing and other aerodynamic advances makes it possible to build a smaller, lighter and more efficient aircraft to perform a given mission.

Among other advances incorporated in the X-29A are a digital "fly-by-wire" control system; flaperons that combine the functions of flaps and ailerons; and forward "canard" wings intended to increase the airplane's agility. The canards replace the customary horizontal tail; their angle relative to the airflow is adjusted by the flight control computer 40 times a second. Another new technology is a system that alters the shape of the wing trailing edge in flight, continually trimming the plane so that it has the best wing shape for a given set of flight conditions.

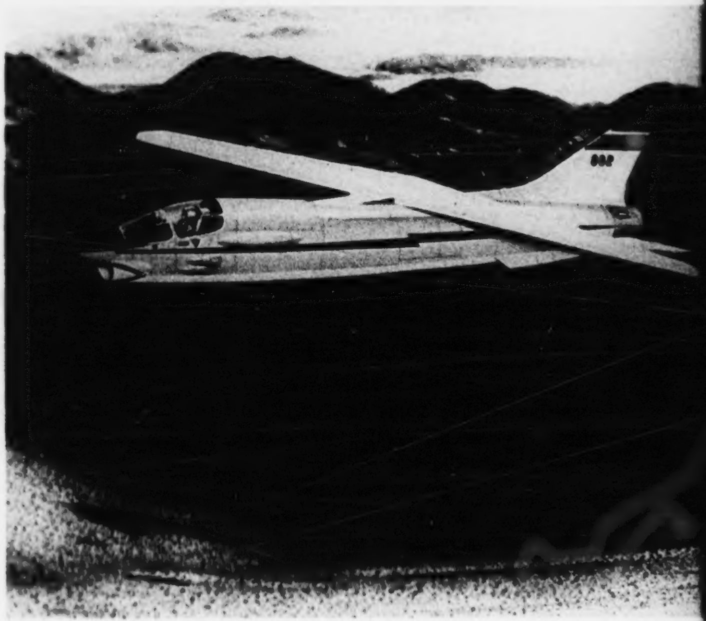


NASA is also participating—jointly with the Air Force—in the Advanced Fighter Technology Integration (AFTI) program, which involves flight testing of aerodynamic and electronic advancements that might be employed in future combat aircraft designs. One project involves testing of the AFTI/F-16 (below), a test bed version of the General Dynamics/USAF F-16. Ames-Dryden Flight Research Facility conducted a Phase 1 program, concluded in 1983, which focused on evaluation of a computerized flight control system and two movable canards located beneath the forward fuselage. After further modification, chiefly new avionic equipment, the AFTI/F-16 was returned to Dryden for Phase 2 testing, now under way. A key element to be investigated in this test series is the aircraft's Automated Maneuvering Attack System, which integrates the computerized flight controls and fire controls to achieve automatic delivery of weapons.

Another AFTI project at Dryden is the AFTI/F-111, also known as the Mission Adaptive Wing (MAW) program. Made of composites, the MAW is a "variable-camber" wing; a computerized system of sensors and controls changes the wing's camber—the fore to aft curve of the airfoil—to get the best aerodynamic configuration for a particular flight condition, for example, approach and landing, cruise, maneuvering or high speed penetration. Under Air Force contract, Boeing Military Airplane Company modified the F-111 fighter to incorporate the variable camber feature. NASA's role, in addition to Dryden's flight test responsibility, includes wind tunnel investigations by Langley Research Center.

In cooperation with the Navy, NASA has embarked on a new program involving tests of an oblique wing aircraft at transonic and supersonic speeds to determine the potential of oblique wing technology for future military and civil applications. A significant departure from conventional design, the oblique wing is one that can be pivoted in flight to form oblique angles with the airplane's fuselage. The wing is perpendicular to the fuselage during takeoff, landing and low speed operation; as the plane flies faster, pivoting the wing to oblique angles reduces air drag. Thus, the concept offers greater aerodynamic efficiency at high speed while maintaining efficiency at low speed.

In 1980–81, NASA conducted a 38-flight program with a small research craft known as the AD-1 and successfully demonstrated the pivoting wing at angles up to 60 degrees. The AD-1, however, was flown only at low speed. The new program will extend the technology to transonic and supersonic speeds with flights up to Mach 1.4 or close to 1,000 miles per hour. The oblique wing (below) will be flight tested on a NASA F-8 airplane known as the Digital Fly-By-Wire (DFBW) research aircraft; the DFBW has been used for several years as a test bed for electronic flight control evaluation. A contractor will be selected this year for preliminary design of the oblique wing, wing box, pivot assembly and flight control system; in 1986, NASA will select a contractor for final fabrication and installation of the oblique wing and its associated systems. First flights are planned for 1988.

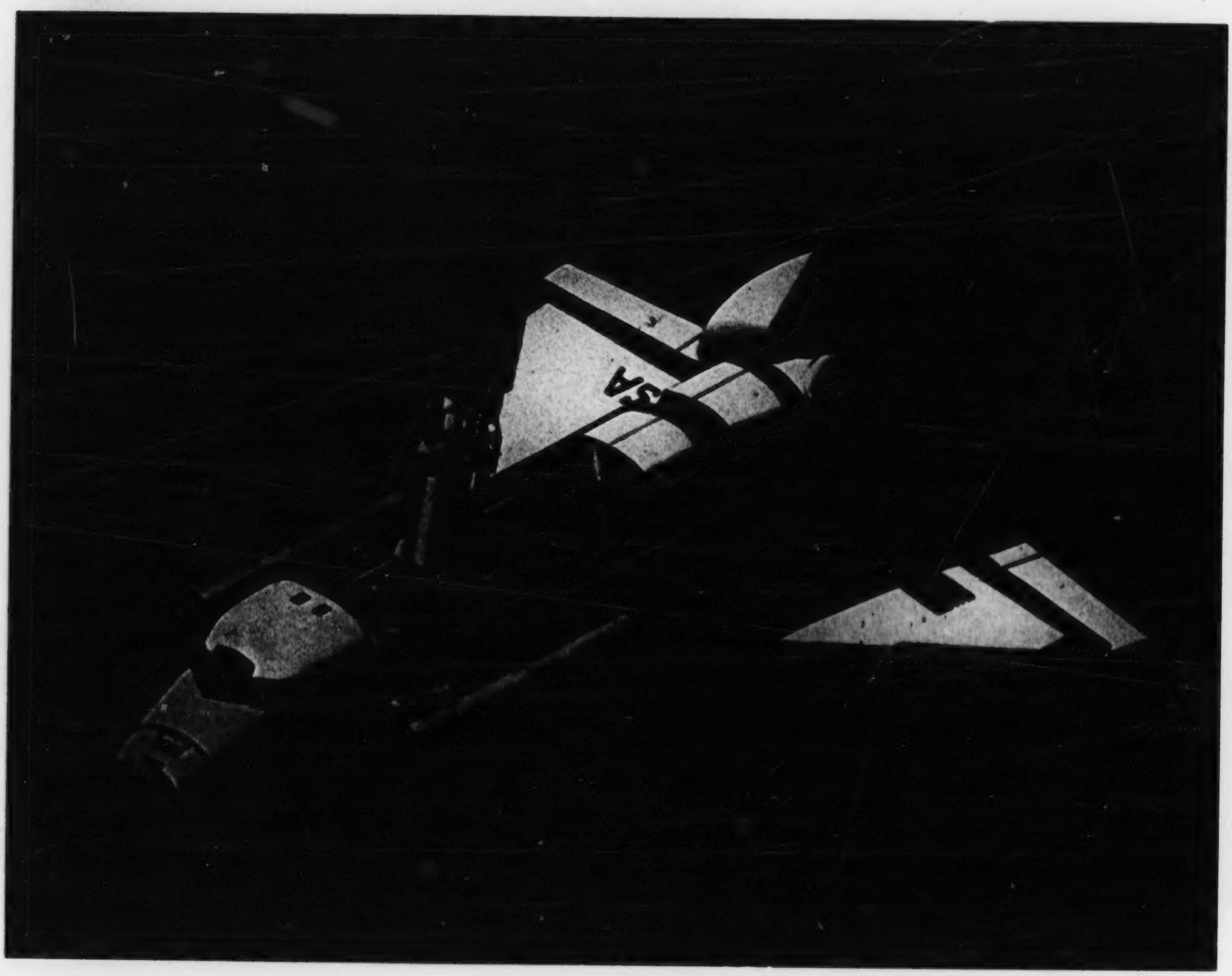


Study of the solar system and the space beyond provides new perspectives on Planet Earth

Probing the Universe

In March 1986, a new space-based astronomical observatory will make its orbital debut. Called Astro and intended for service aboard several Space Shuttle missions, it consists of three telescopes designed to study celestial bodies in ultraviolet light, which is largely invisible to ground observatories because it is absorbed and filtered by Earth's atmosphere.

On its initial flight, Astro will have a special assignment:



observation of Comet Halley as the comet makes its once-every-76-years close approach to the Sun. Astro's three telescopes will be co-aligned for simultaneous ultraviolet imaging of the comet; observatory instruments will measure the ultraviolet light's wavelengths and intensities as a means of determining Halley's structure and composition. For this initial seven day mission, the Astro system will also include two wide field cameras for photographing Halley in visible light.

The Space Shuttle's launch is timed so that Astro will be in operation about a month after perihelion, the point at which Halley will come closest to the Sun. Astro's observations will thus coincide with and complement those made by five cometary close encounter probes operated by the European Space Agency, Japan and the Soviet Union. This timing was dictated by the fact that, at perihelion, the comet will be behind the Sun, hence not visible to Earth observatories or Earth-orbiting spacecraft.

Next March, a new Shuttle-based observatory called Astro (left) will view Comet Halley from Earth orbit. The Pioneer Venus Orbiter (above) will also observe the comet from a special vantage point in Earth orbit.

Generally similar but different in design specifics, the three telescopes represent the work of three separate organizations. The Hopkins Ultraviolet Telescope, being developed by Johns Hopkins University, will make measurements expected to reveal Halley's chemical composition. The University of Wisconsin's Ultraviolet Spectropolarimeter will investigate the formation and destruction of dust in the comet's tail. The Ultraviolet Imaging Telescope, being developed by Goddard Space Flight Center, will be used to determine the overall cometary structure and to observe the effects of Halley's post-perihelion passage, when the Sun's energy boils off significant amounts of material from the comet's nucleus, creating the long tail. The wide field cameras will photograph the tail in large scale; they are being developed by Marshall Space Flight Center, which is also project manager for the Astro program.

In addition to Astro, NASA plans to make Halley observations with instruments aboard already orbiting spacecraft:

- The Pioneer Venus Orbiter, which has been circling Venus since 1978, will observe the gases and dust emanating from Halley through its ultraviolet spectrometer. The spacecraft will have a prime vantage point for perihelion observations because Venus will be on the opposite side of the Sun from Earth and will be the celestial body nearest the comet at perihelion.
- The International Ultraviolet Explorer, operating in a high altitude Earth orbit, will also make a spectroscopic analysis of Halley material.
- The Solar Maximum Observatory, the subject of history's first on-orbit repair job last year, will use a coronagraph to make images of the comet and a spectrometer to examine Halley's nucleus.

Aside from flight activity, NASA will play a leading role in coordinating the flow of Halley information from the international fleet of spacecraft, from ground observatories and from instruments aboard aircraft, sounding rockets and balloons. All this information will be channeled to a central archive operated by the International Halley Watch (IHW), staffed by scientists of many nations. NASA is co-sponsor—with West Germany's University of Erlangen-Nurnberg—of the IHW.

NASA's multifaceted participation in Comet Halley observations exemplifies a part of the agency's work known as the space science and applications program. Applications involve use of space technology to generate direct public benefit on Earth. Examples include technology for communications and weather satellites, which NASA pioneered in the 1960s; among more recent examples are remote sensing satellites for Earth resources survey, a space-based system designed to aid search and rescue operations, and development of advanced technology for a new generation of high capacity communications satellites.

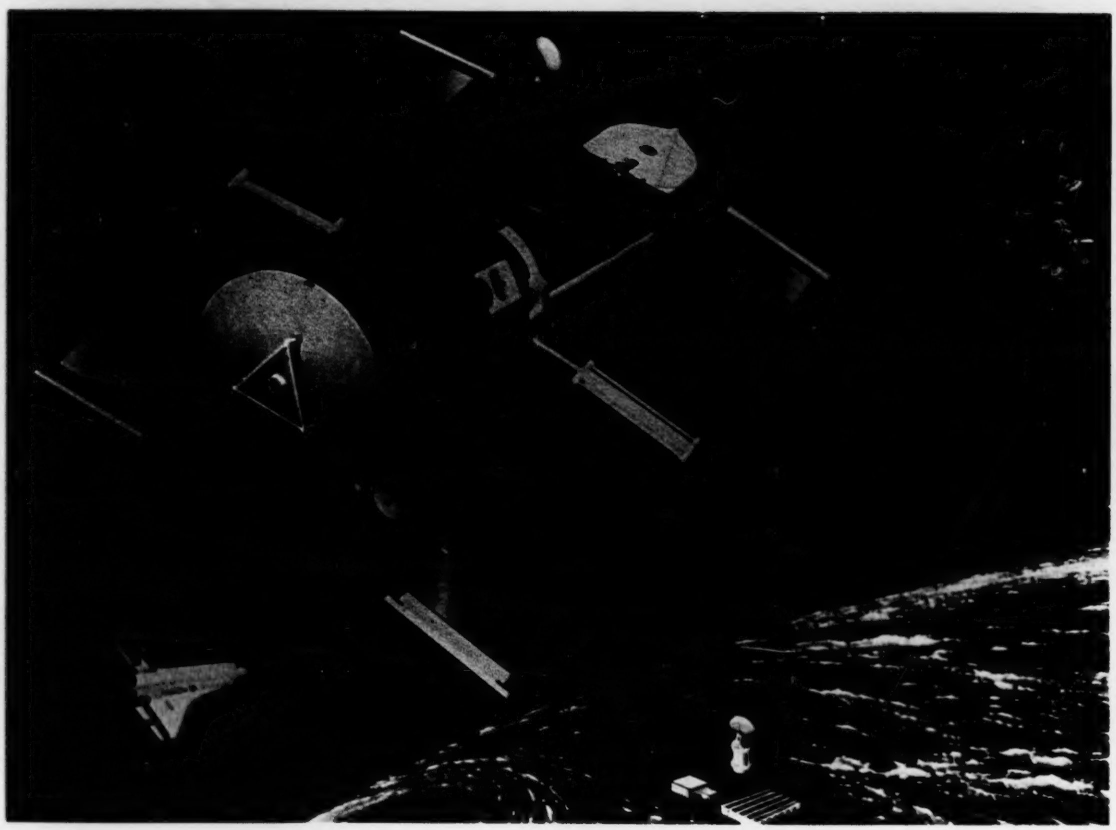
The space science program has four main avenues of effort: solar system research, or investigation of the planets and other objects within the solar system; solar terrestrial research, study of the Sun's energy processes and their interactions with Earth's environment; astrophysics research, study of the distant stars and galaxies; and life sciences research aimed at understanding the origin and distribution of life in the universe. The latter area also seeks improved knowledge in medicine and biology through utilization of the space environment. This comprehensive program has many goals, but they can be reduced to a common denominator: fitting Planet Earth into the ever-expanding informational mosaic of how the universe began, how it evolved and how it is structured.

Ulysses

The ecliptic is a great circle, or plane, that approximates an imaginary extension of the Sun's equator. Earth and the other planets revolve about the Sun in orbits close to the ecliptic plane. All spacecraft launched to date have similarly operated close to the ecliptic. Thus there is a scientifically important region of the solar system yet to be explored: the area out of the ecliptic. The first effort to investigate this spatial third dimension will get under way in May 1986 with the launch of a spacecraft aptly named Ulysses, for the mythological hero who—in Florentine poet Danté's *Divine Comedy*—sought to explore the "uninhabited world behind the Sun." The spacecraft Ulysses will explore a new "world" by flying around the Sun's poles.

Formerly named the International Solar Polar Mission, Ulysses is a joint project of the European Space Agency (ESA) and NASA. ESA is developing the spacecraft and about half of the scientific payload; NASA will provide the rest of the payload and the spacecraft's power generating system. NASA will also Shuttle-launch Ulysses into the out-of-the-ecliptic trajectory and support the mission using its Deep Space Communications Network. Jet Propulsion Laboratory is NASA's project manager.

Ulysses will investigate, from its new perspective, such phenomena as the solar wind, an electrified gas coursing outward from the Sun at a million miles per hour; solar and galactic radiation; cosmic dust; and solar/interplanetary magnetic fields. The spacecraft's initial trajectory will take it on a 14-month flight to Jupiter, where the giant planet's immense gravity will be utilized as a "slingshot" to hurl the spacecraft out of the ecliptic plane. After two and a half years on this new trajectory, Ulysses will pass over one of the Sun's poles; then it will recross the ecliptic en route to the other pole, which it should reach about eight months later. The entire mission will take five years.



Space Telescope

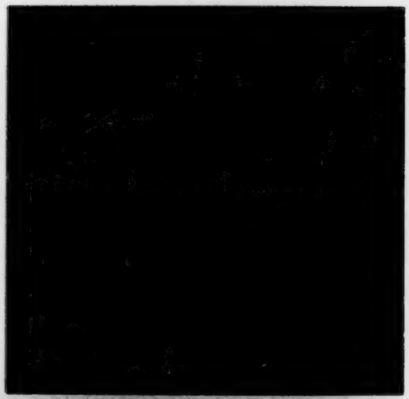
To be launched next year after a decade in development, the Edwin P. Hubble Space Telescope is potentially the most dramatic advance in astronomy since the invention of the telescope in the 17th century. Operating above Earth's atmosphere at an altitude of 320 miles, the orbiting observatory will be free of atmospheric distortions that limit the vision of ground-based telescopes. Thus it will be able to "see" seven times farther into space, pick up objects 50 times fainter and return images with at least 10 times better clarity—in all, it will literally look back into time some 14 billion years and expand man's view of the universe about 350 times.

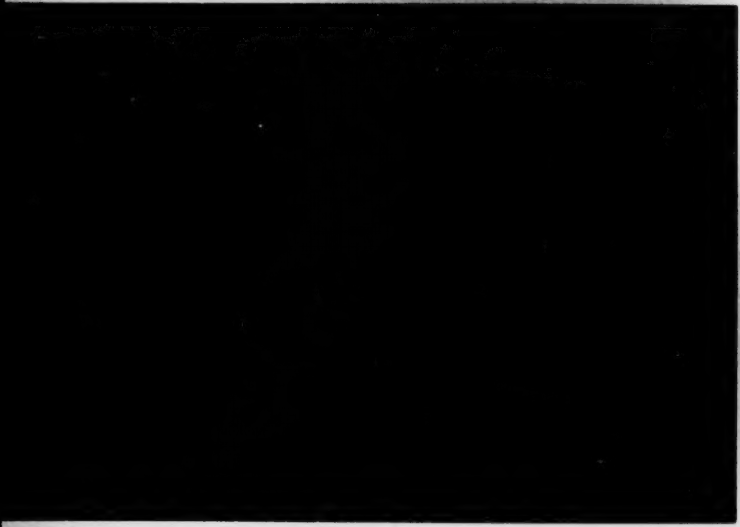
Forty-three feet long and weighing more than 25,000 pounds, the Hubble Space Telescope will be the largest scientific payload ever sent into orbit. Periodically serviced by Space Shuttle crews, the observatory is expected to operate at least until the year 2000. The telescope employs a system of mirrors to "capture" starlight, photograph it and analyze it; analysis of the visible and ultraviolet light from celestial bodies provides information on the chemical and physical composition of the objects viewed.

Star images and instrument data will be relayed to Goddard Space Flight Center, which will have responsibility for controlling the telescope and processing its data. Goddard will forward the processed data over land lines to the Space Telescope Science Institute in Baltimore, Maryland, the center for collection, study and distribution of scientific data acquired by the Hubble observatory.

Lockheed Missiles & Space Company, Sunnyvale, California, is integrating the Optical Telescope Assembly, heart of the system, with the Lockheed-built Support Systems Module, which houses the optics and associated instruments along with power, communications and data management systems. The 30-foot-long Optical Telescope Assembly, which includes the mirror system and associated electronics, was built by Perkin-Elmer Corporation, Danbury, onnecticut. The European Space Agency furnished one of the five primary instruments and the electricity-generating solar array. Marshall Space Flight Center has overall management for the Hubble Space Telescope project. Lockheed will complete assembly and checkout of the various observatory components later this year and ship the complete spacecraft to Kennedy Space Center for launch aboard the Space Shuttle next August.

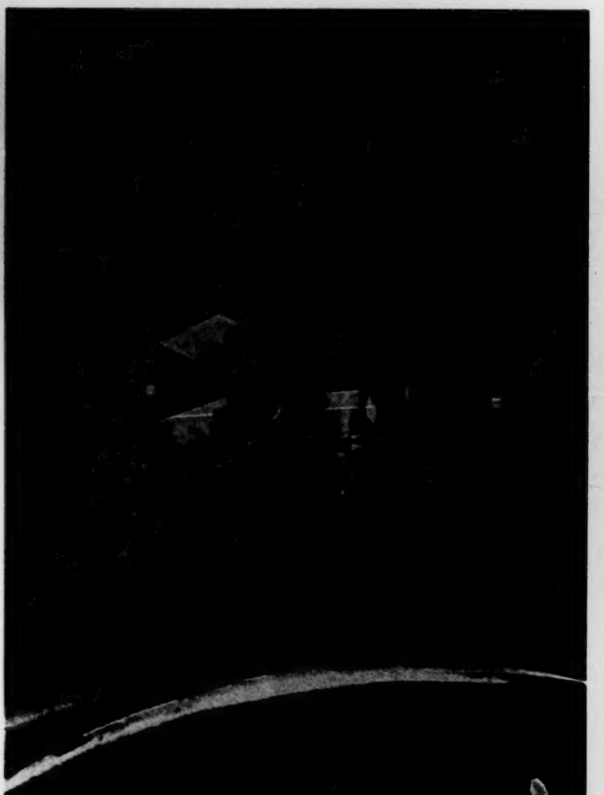
Orbiting Observatories





Visible light represents only a small portion of the radiations emanating from celestial bodies. Thus, a comprehensive astronomy program requires not only optical telescopes viewing visible light but complementary systems capable of observing the non-visible radiations emitted by celestial objects, because each area of the electromagnetic spectrum offers a different set of clues to the origin and evolution of the universe. Space-based systems play a particularly important role in this type of research because they operate above Earth's blanket of atmosphere that absorbs virtually all of these non-visible radiations.

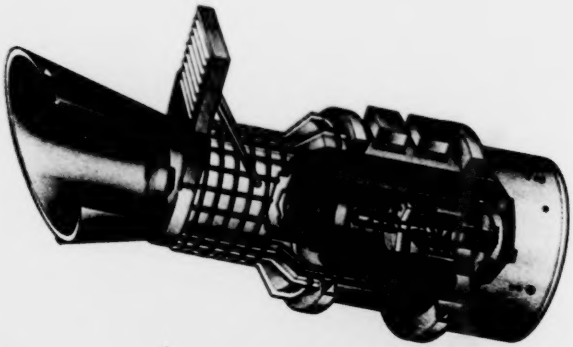
Over a span of more than two decades, NASA has been using orbital systems to observe and analyze non-visible emanations from distant space—such as x-rays, ultraviolet light and infrared radiation—and has demonstrated the exciting potential of this type of astronomy for unlocking the secrets of the universe. NASA is now developing—separately and in cooperation with research organizations of other



nations—an advanced family of orbiting observatories designed to explore particular ranges of the electromagnetic spectrum.

NASA satellites such as Uhuru (1970) and HEAO-2 (1978) provided a base of knowledge about x-ray emissions from a wide variety of celestial objects, including stars, pulsars and galaxies.That knowledge base will be considerably expanded by a new x-ray observatory being developed jointly with the German Federal Ministry for Research and Technology. Called ROSAT, for Roentgensatellit (opposite page, upper left), it will be launched in 1987 to conduct an all-sky survey of x-ray sources and make dedicated observations of specific sources for extended periods of time. This will allow astronomers to study in greater detail many of the phenomena discovered by earlier x-ray satellites. West Germany will build the ROSAT spacecraft and the x-ray telescope; NASA will provide a high resolution imaging system and Space Shuttle launch services. Goddard Space Flight Center and the German Aerospace Research Establishment are responsible for managing the U.S. and German portions of the program.

NASA plans an even more advanced x-ray observatory for the 1990s, a 10-ton satellite known as the Advanced X-ray Astrophysics Facility (AXAF), whose instruments will be about 100 times more sensitive than those of ROSAT. Intended to operate for at least 15 years by means of on-orbit servicing by Space Shuttle crews, AXAF (opposite page, lower left) will study x-ray emissions from virtually all known astronomical objects, ranging from nearby stars to quasars at the edge of the universe. Marshall Space Flight Center manages the AXAF program.

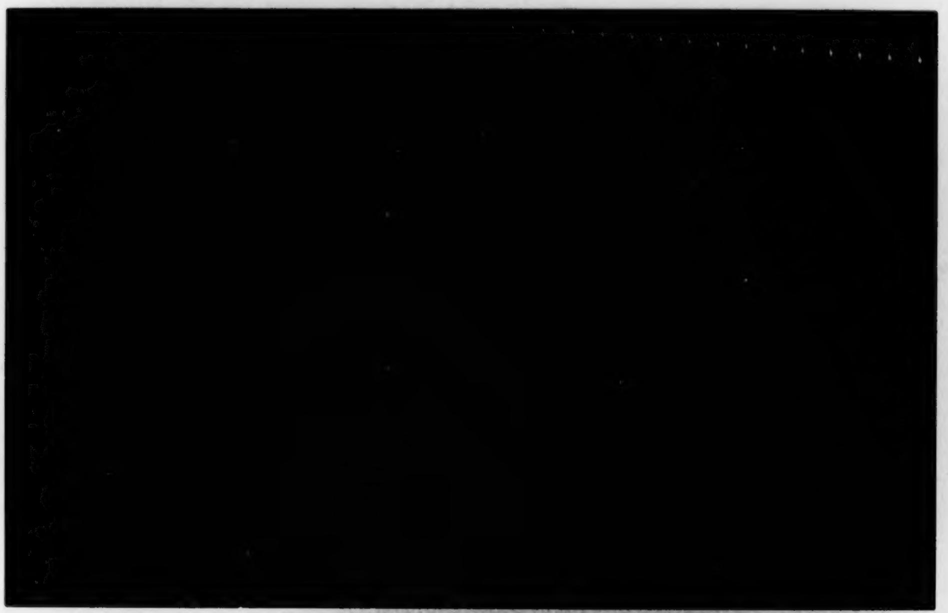


In development for 1987 launch is a spacecraft called EUVE, for Extreme Ultraviolet Explorer (left center). Extreme ultraviolet refers to a certain wavelength range within the ultraviolet region, a portion of the spectrum that has never been surveyed. EUVE's observations are expected to contribute to better understanding of the late stages in the lives of stars. The project is managed by Jet Propulsion Laboratory.

In 1983, NASA's Infrared Astronomical Satellite (IRAS), made the first all-sky survey of infrared emissions, mapping some 100,000 sources and detecting a variety of never-before-seen infant stars, dying stars and other cold and cool objects that do not shine in visible light. A planned follow-on to IRAS, with instruments 1,000 times more sensitive, is the Space Infrared Telescope Facility (SIRTF), shown in cutaway view at left below. Like IRAS, SIRTF's optics and interior will be cooled by a cryogenic to a few degrees above absolute zero, theoretically the lowest temperature possible; the reason for such supercooling is that detecting faint infrared (heat) radiations from distant space requires that the amount of heat emitted by the telescope itself must be minimized. Planned for service in the early 1990s, SIRTF will be used to study a broad range of objects from bodies orbiting in the solar system to galaxies forming at the edge of the universe.

To expand upon basic data in the field of gamma radiation provided by spacecraft of the 1970s, NASA is developing—jointly with West Germany, The Netherlands and the United Kingdom—the Gamma Ray Observatory (GRO), which is to be launched in 1988. Gamma rays are the most energetic form of radiation known; a gamma ray unit packs a million to a trillion times as much energy as a comparable unit of visible light. These rays offer insight into the violent aspects of the universe—explosive, high energy and nuclear phenomena—that are found in such puzzling objects as pulsars, quasars, black holes and supernovae. GRO (left) will give scientists an opportunity to study many cosmic phenomena of particular importance, such as the origins of high energy gamma ray bursts, the nuclear processes occuring near neutron stars and black holes, and the nature of recently discovered gamma ray sources in our own Milky Way galaxy. Goddard Space Flight Center manages the project.

Planetary Exploration

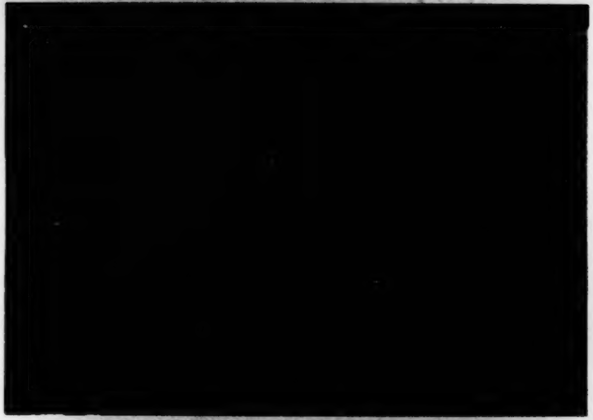


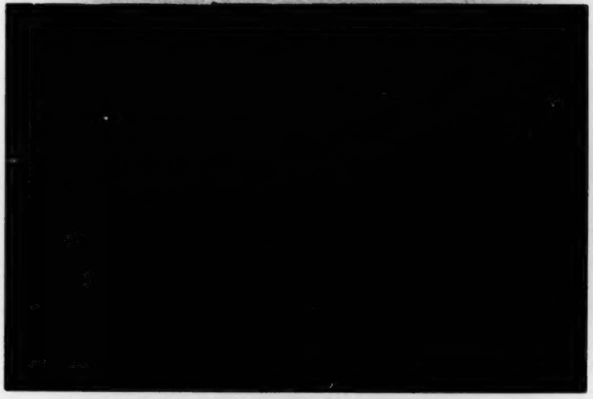
Since 1981, when two Voyager spacecraft concluded their reconnaissance of Saturn, planetary exploration has been at low ebb. But beginning next year and continuing into the 1990s, there will be a resurgence of planetary/interplanetary research activity. Some of it involves encounters with planets never before visited by spacecraft; other missions include long term, detailed investigation of planets already reconnoitered, but briefly.

The first new encounter will come next January 24, when Voyager 2, now eight years out of home port Earth, will fly by Uranus (top), the seventh planet from the Sun. Voyager 2 has already returned images of Uranus from distances up to 350 million miles; in January it will send the first closeup views of the planet as it passes within 64,000 miles. This is a mission of prime scientific importance because Uranus, orbiting the Sun at a distance of 1.8 billion miles, is only dimly visible to Earth telescopes.

Even less visible, because it is a billion miles farther, is Neptune, the eighth planet. If Voyager is still functioning after it completes its reconnaissance of Uranus, it will continue on to Neptune for an encounter in 1989 when the spacecraft is 12 years and some 2.8 billion miles from Earth.

While Voyager is en route to Neptune, NASA will send the Galileo spacecraft on a mission to Jupiter. Planned for launch in May 1986 (above right) and arrival at Jupiter in December 1988, Galileo may make the first encounter with an asteroid while en route to its primary target. The Galileo mission is being planned with a trajectory option, so that mission controllers can decide after launch whether to proceed with the asteroid flyby. The target is Amphitrite, a large asteroid about 125 miles in diameter. Galileo would fly within 6,000 to 12,000 miles of the asteroid, photograph it and scan it by means of spectrometers. If the option is exercised, the asteroid encounter will take place in December 1986.

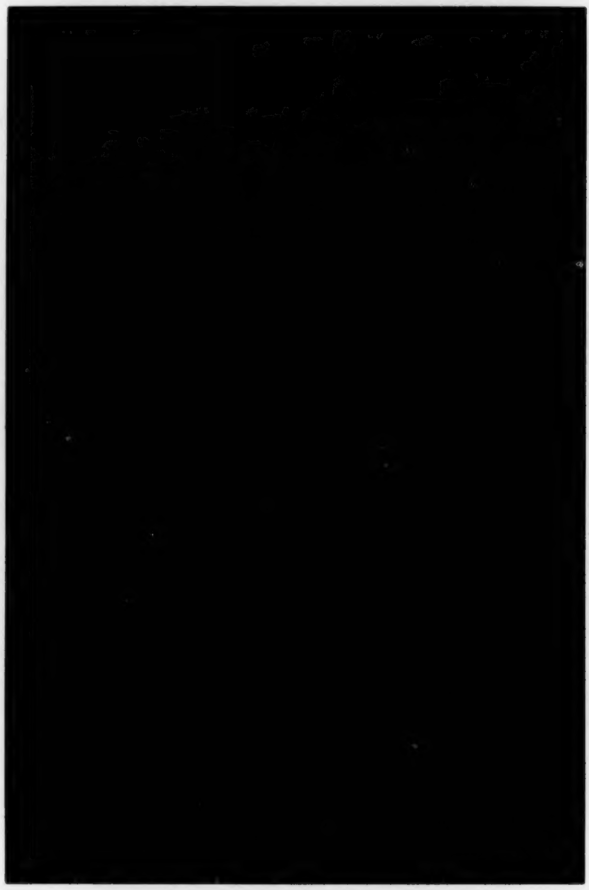




In the summer of 1988, while still five months from Jupiter, Galileo will release a five-foot-diameter entry probe to descend into the Jovian atmosphere (above). Containing seven instruments and protected by a heat shield from temperatures expected to reach 14,000 degrees Fahrenheit, the probe will report data—

relayed to Earth through the main spacecraft—on temperature, pressure and atmospheric composition. Its lifetime in the extreme heat and crushing pressure of the Jovian atmosphere is estimated at 60 to 75 minutes, but in that brief time it can provide volumes of exceptionally important scientific data—important because Jupiter's gaseous atmosphere is believed to contain samples of the original material from which the solar system was formed, hence the probe may contribute valuable information about the origin and development of the solar system.

On arrival at Jupiter, the main spacecraft will swing into an orbit around the giant planet and begin transmitting high quality images and instrument data concerning Jupiter and its moons. Galileo will, in effect, become a moon of Jupiter, orbiting over a period of 22 months to report on Jovian phenomena from many different vantage points, sending some 50,000 high resolution images and enormously amplifying the body of knowledge acquired by four prior spacecraft reconnaissances. Galileo is a cooperative program with the Federal Republic of Germany. Jet Propulsion Laboratory is project manager and builder of the main spacecraft; Ames Research Center has responsibility for the probe, which is being built by Hughes Aircraft Company and General Electric Company.



Planned for launch in 1988 is another planetary explorer known as the Venus Radar Mapper (right), which will use an advanced type of radar to map virtually all of Venus' surface, never seen by optical telescopes because the planet is permanently cloud-shrouded. This research will amplify an earlier Venus mapping effort by the Pioneer Venus Orbiter, which began in the late 1970s. Where the maps generated by the latter spacecraft showed only large scale Venusian features, the Venus Radar Mapper will provide resolutions 10 times better; that will enable identification of such small scale features as volcanos, impact craters, lava flows, tectonic faults, erosion channels and possibly the remnant shorelines of long-ago oceans. Such information is a major step toward determining the geological history of the neighbor planet, scientifically important because it can lead to greater knowledge of Earth's own complex environment. The Venus Radar Mapper program is managed by Jet Propulsion Laboratory.

A new planetary program, planned for launch about 1990, involves a long-term investigation of Mars designed to expand knowledge of the Red Planet acquired in earlier missions. Known as the Mars Observer, the spacecraft will carry advanced instrumentation to determine the surface composition of Mars on a global scale and to provide detailed data on the planet's atmosphere and meteorology. This is part of a continuing study of the Earth-Venus-Mars triad. Although seemingly very different, the three neighboring planets exhibit a number of common characteristics; detailed comparison studies are intended to advance understanding of the evolution of Earth and the inner solar system.

Ocean Observation Systems

For the better part of two decades, NASA has been developing technology for satellites that monitor changing conditions on Earth. The most notable development was the Landsat series of Earth resources survey satellites operated for 13 years, initially by NASA and later by the National Oceanic and Atmospheric Administration (NOAA). NASA also developed—and operated for a three month period in 1978—a microwave satellite called Seasat, a highly successful experiment in collecting data on changing conditions at the surface of the world's oceans. Since Landsat's capabilities have been thoroughly demonstrated and the system is now ready for commercial operation, NASA is focusing research attention on ocean monitoring systems, which offer dual potential for scientific studies and practical applications.

A major project involves development of a "scatterometer," a microwave system that enables calculation of wind speeds and directions by measurement of radar reflections from the waves on the ocean surface. NASA's Seasat scatterometer provided the first global measurements of ocean wind data. NASA is using that technology as a departure point for development of a more advanced scatterometer—called NSCAT—that will be a key component of the Navy Remote Ocean Sensing System (NROSS), planned for initial use in 1990. A Navy-led cooperative project involving NASA, NOAA and the Air Force, NROSS will collect global wind data as a basis for studying waves, ocean circulation and the interaction between the oceans and the atmosphere. The driving forces for waves and currents, sea surface winds also influence the exchange of heat between the atmosphere and the seas. On a global scale, winds and currents redistribute excess solar heat from the tropics to the cooler polar regions. Since both the oceans and the atmosphere transport heat from the equator to the poles, knowledge of ocean/atmosphere dynamics provided by NROSS will contribute to improved understanding of world climate.

Shown in the accompanying photo is another planned ocean observation system known as TOPEX (Ocean Topography Experiment), to be developed by NASA for operation beginning about 1990. A much advanced successor to Seasat, TOPEX is designed to make highly accurate measurements of sea surface elevations over entire ocean basins for several years. Integrated with subsurface measurements, this information will be used in models to determine ocean circulation and its variability.

TOPEX will report continuously on such changing factors as wave heights and directions, surface winds, current and tide patterns. It will provide improved knowledge of ocean dynamics for scientific studies and will also offer many opportunities for practical benefit in such areas as weather and climate prediction, coastal storm warning, maritime safety, waste disposal, ship design, ship routing and food production from ocean sources.

Space Communications

In the early 1960s, NASA pioneered technology for operation of communications satellites in geostationary orbit (22,300 miles) and thus built the foundation for what is a very large complex of international, domestic and special purpose commercial communications systems. But the dramatic growth of space communications has created a problem. The number of geostationary orbit "slots" available for communications satellites is necessarily limited—because proximity can cause one satellite's signals to interfere with another's—and the orbit is becoming crowded. This orbital congestion poses a barrier to further expansion which, according to projections, will be necessary to meet greatly increased traffic demand in the 1990s and beyond. The answer to easing this possible logjam is new technology to enable large increases in the message handling capacities of individual satellites.

The multibillion dollar market for commercial communications satellites has attracted a number of foreign competitors in a business traditionally dominated by U.S. satellite manufacturers. Japan and several European nations have embarked on development of high capacity satellites intended for service in the 1990s. To maintain U.S. leadership in this field and to make available to American manufacturers the technology they need to compete effectively, the Congress has directed NASA to undertake a new technology advancement effort.

Such a program was initiated last year with the award of a contract to RCA Astro-Electronics for design and development of an Advanced Communications Technology Satellite (ACTS); an artist's conception of ACTS is shown at right.

ACTS will incorporate a number of new capacity increasing technologies, in particular a "spot beam" approach. In this technique, advanced satellite equipment would generate multiple message-carrying spot beams, each focused on a narrow Earth region, rather than the wide beams now generated. Spot beams operating in the same frequency can handle many messages without interfering with one another, thus offer potential for multifold expansion of satellite capacity. But successful employment of this technique requires extensive technology development—new types of antennas in space and on the ground, and a complex, computer-directed switching system on board the satellite to shift the beams rapidly among target spots on Earth. Intended as a proof-of-concept demonstrator rather than a prototype commercial satellite, ACTS is planned for launch from the Space Shuttle in 1989.

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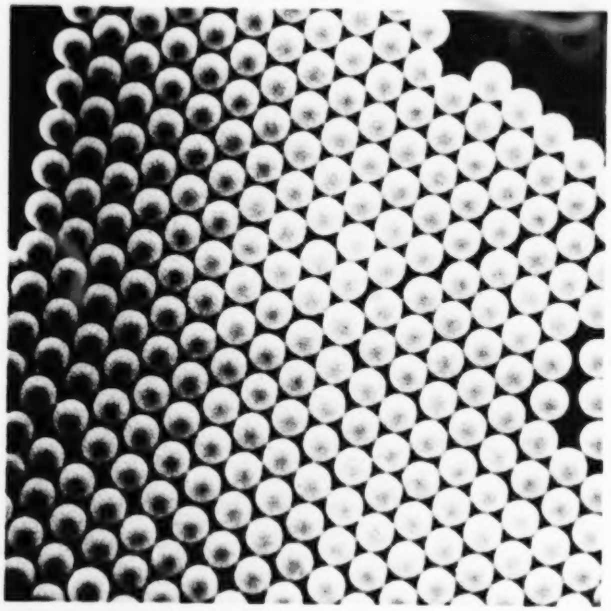
NASA seeks to stimulate private investment in orbital ventures to assure U.S. leadership in a promising new field of space endeavor

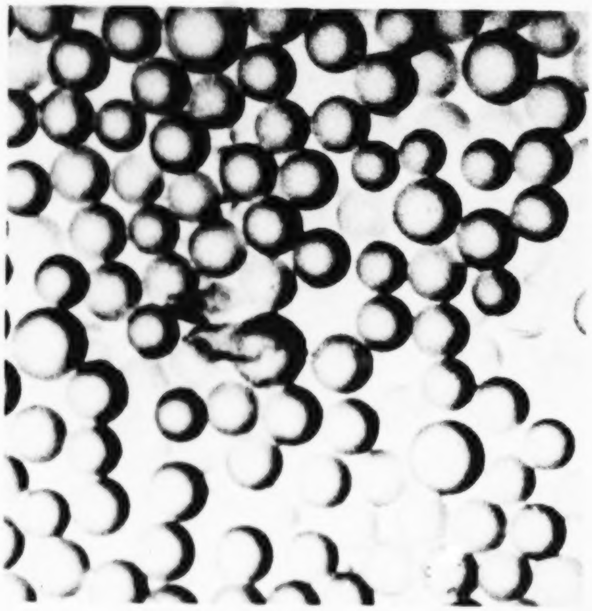
Commercial Use of Space

This year marks the introduction to the commercial marketplace of the first products made in space. They are "microspheres," plastic beads so tiny that a vial containing 15 million of them is no larger than an index finger. Each is a perfect sphere whose diameter is 10 micrometers—1/2500th of an inch or 1/40th the diameter of a human hair—and all are identically sized. They fill an important need among research and industrial laboratories as a reference standard for calibrating instruments—for example, microscopes or automatic blood cell counters—with extreme accuracy. They can also be used, by companies seeking to comply with environmental regulations, for measuring air pollution particles; by paint or ink manufacturers for measuring finely-ground pigments; or by oil, gunpowder, cosmetic or other companies who have a requirement for precise measurement of microscopic particles. They are particularly valuable in medical research, where they offer utility in such applications as measuring drainage channels in the eyes of glaucoma victims or, in cancer research, determining with high accuracy the size of intestinal wall pores.

What makes the latex microspheres important is that they cannot be made on Earth in the sizes laboratories want and in sufficient uniformity. On Earth, it is possible to grow in quantity spheres in sizes up to three or four micrometers; beyond that, gravity distorts the shape, making some beads oval rather than round, some larger than others, and some stuck together in clumps.

Made of polystyrene, the material used in disposable drinking cups, the microspheres were made on four 1982–84 Space Shuttle flights by use of new techniques and equipment jointly devised by scientists at Lehigh University and Marshall Space Flight Center (MSFC). They were grown in an apparatus, developed by MSFC, known as the Monodisperse Latex Reactor (MLR); monodisperse means





identical size. Housed on the Shuttle Orbiter's mid-deck, the MLR consists of four one-foot-tall chemical reactors, or furnaces, in which a latex mixture containing thousands of tiny nuclei—seeds—is heated and stirred; in a manner analagous to the way oysters grow pearls, a heat-induced chemical reaction causes the spheres to grow as the mixture coagulates around the seeds.

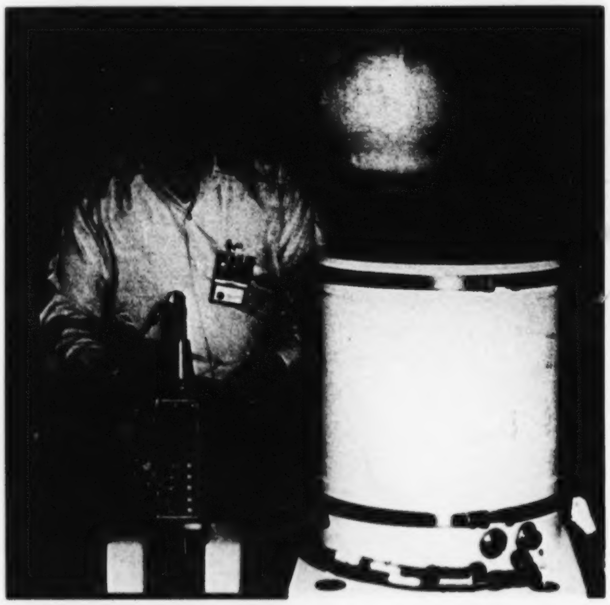
In 1984, NASA turned over to the National Bureau of Standards (NBS) 25 grams of microspheres for certification as standard reference materials; the amount is less than an ounce. Employing several sophisticated measurement techniques to confirm the size and uniformity of the spheres, NBS subsequently certified that they deviate from the 10-micrometer size by no more than one hundred millionth of a meter. The spheres were then divided into several hundred small vials for sale to researchers. Income from the sales—potentially about $250,000—will be shared by NASA and NBS to defray the costs of producing and certifying the spheres.

In addition to the 10-micrometer spheres, the initial series of Shuttle-based MLR runs also yielded experimental microspheres measuring five to 30 micrometers. In a new series planned for 1986, NASA will attempt to grow larger latex microspheres ranging up to 100 micrometers. Future availability in quantity of bigger, uniform spheres would open the door to a variety of medical, scientific and industrial research activities not currently feasible. Estimates indicate that the world market potential for microspheres, in instrument calibration alone, is on the order of $200–300 million annually; that could increase to $1 billion a year with widespread acceptance of the spheres in other applications identified.

The NASA/Lehigh microsphere program exemplifies the promise of processing materials in the airless, gravity-free environment of space to manufacture a variety of products that cannot be produced effectively or in quantity on Earth. Among such products are medicines for improved treatment of many diseases; semiconductor materials with enormously improved electrical properties for great advances in electronics; extremely pure glass for such applications as laser or optical systems; and vastly superior metallic alloys for a multitude of applications. Those are the principal possibilities already identified, but the history of technology development suggests that continuing research and greater familiarity with the space processing environment will reveal many important applications not currently imaginable.

The key to realization of the space manufacturing promise is private investment in commercial ventures. NASA seeks to encourage such investments through a number of measures. The agency is supporting research aimed at commercial applications, providing easier industry access to NASA research facilities and promoting NASA/industry information exchanges. To reduce industry's financial risks, NASA will continue to offer reduced rate Shuttle space for high technology experimentation and assist in integrating commercial equipment with the Shuttle. This government support of industry is designed to assure U.S. leadership in a burgeoning new field of space endeavor and to foster establishment of new industries, contributing thereby to expanded employment and an enhanced U.S. competitive position in international trade.

These photos graphically illustrate the effects of gravity, or the lack of it, on materials undergoing processing. The tiny beads, here magnified 500 times, are microspheres used in research laboratories. Those at far left, all perfect spheres and identically sized as required by the laboratories, were grown in orbit free of gravity; those at left, variously sized, some egg-shaped, others stuck together, were grown on Earth with the same equipment.



A Marshall Space Flight Center researcher is checking the NASA-developed Monodisperse Latex Reactor used to grow perfectly uniform microspheres on Space Shuttle flights. The white canister at right is the reactor's housing.

Materials Processing

In November 1984, 3M Company conducted its first commercial materials processing experiment aboard the Space Shuttle. Flown on Shuttle mission 51-A, the experiment was termed by company officials an "unqualified success." Called DMOS—for Diffusion Mixing of Organic Solutions—the 3M experiment was an investigation of zero gravity organic chemistry, specifically a study of space-grown crystals, which can be grown larger and more nearly flawless than on Earth, hence have potential for many important applications in electronic, optical and communications systems. The initial company emphasis is on basic research rather than product development. 3M scientists are conducting extensive examinations of the space-grown crystals, checking them for properties that might ultimately find applications in the company's basic business areas—imaging, electronics and health care.

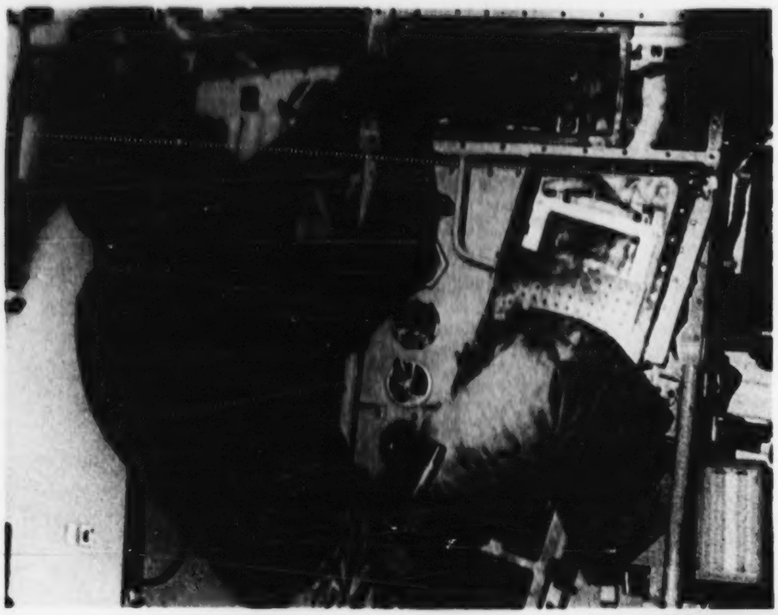
The 3M apparatus on flight 51-A consisted of six chemical reactors housed in the Orbiter *Discovery's* mid-deck during the eight-day mission. The reactors produced hundreds of crystals grown from heated liquid compounds of several different types; most of the crystals were larger and more free of defects than Earth-grown crystals. The symbolic composite photograph (above right) shows a group of needle-shaped crystals grown from urea, a substance commonly used in synthesis of plastics. At right is a batch of large crystals grown from a proprietary compound.

3M Company is continuing its orbital research on three 1985 Shuttle flights, operating under a Joint Endeavor Agreement (see page 120) with NASA. The company has also submitted a proposal for a 10-year agreement, which would involve 72 3M Shuttle flights between 1985 and 1995 with the goal of research and product development in the areas of organic and polymer science. In addition, 3M has established a new Space Research and Applications laboratory at its St. Paul, Minnesota headquarters.

A number of other companies are preparing experiments in various aspects of space crystal growing. They include Microgravity Research Associates, a new company formed specifically to pursue materials processing research, and three major aerospace firms: Grumman Aerospace Corporation, Boeing Aerospace Company and Honeywell Inc. Another aerospace company—Martin Marietta Corporation—is planning Shuttle-based research in fluid dynamics and The DuPont Company is conducting ground-based microgravity simulation research on catalytic materials.

The most comprehensive space materials processing effort yet accomplished is the Electrophoresis Operations in Space (EOS) program, an exploration of the commercial feasibility of space-processed pharmaceuticals conducted by McDonnell Douglas Astronautics Company and its EOS partner, Ortho Pharmaceutical Corporation, a division of Johnson & Johnson. McDonnell Douglas has operated the EOS biological materials processing system on several Shuttle flights; the system separates materials in solution by subjecting them to electrical stimulation in a computer-controlled process. At upper right, McDonnell Douglas engineer Charles D. Walker is checking the EOS system; Walker became the first "commercial astronaut" when he flew as a payload specialist aboard a 1984 Shuttle mission.

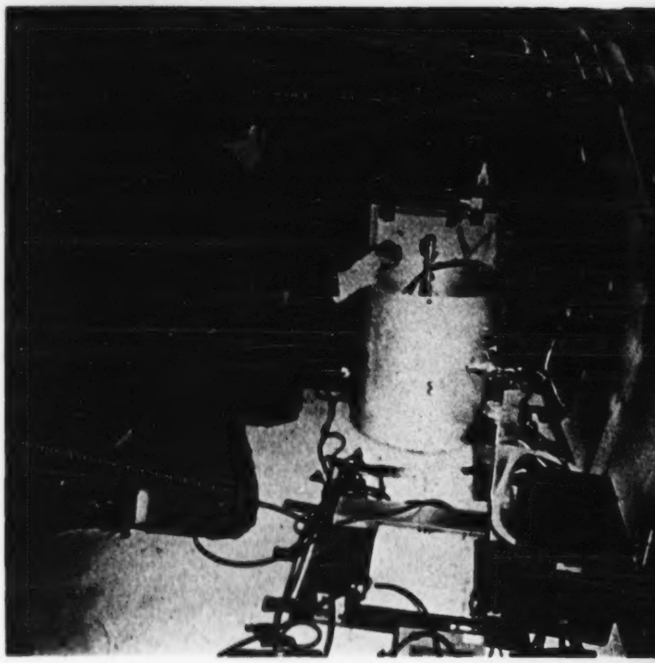
The EOS project is aimed at separating biological materials—cells, enzymes, hormones and other



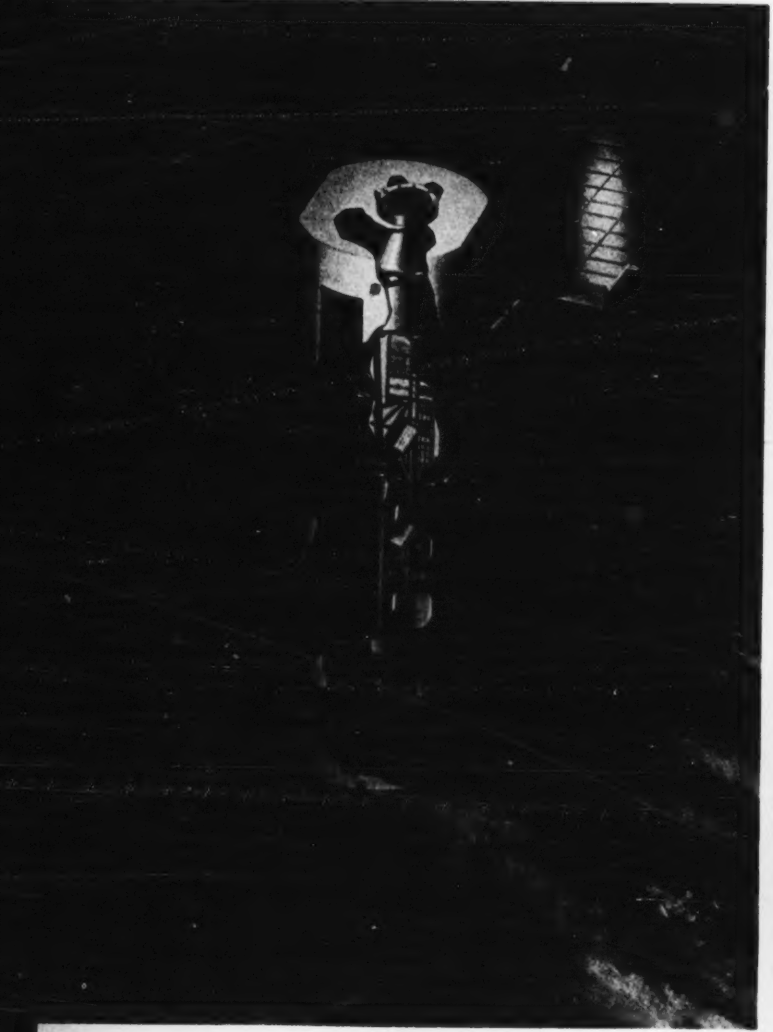
proteins—in sufficient quantities and purities to enable production of pharmaceuticals for more effective treatment of many diseases. In Shuttleborne tests, the EOS system has demonstrated its ability to produce more than 700 times the material that could be extracted from similar Earth processing, with a fourfold increase in purity. McDonnell Douglas and Ortho hope to make their first space-processed pharmaceutical product available for public use within this decade.

Still another area of commercial potential is space-based metallurgy, which theoretically promises vastly superior metallic alloys for a multitude of uses. A major manufacturer—the farm equipment firm Deere & Company—is researching this field but with a different perspective: Deere has no plans to manufacture products in space, but wants to study iron processing under weightless conditions with the aim of developing new Earth processing techniques for improving the strength and quality of cast irons.

Deere & Company has learned a great deal from experiments in a furnace developed by Marshall Space Flight Center, flown aboard NASA aircraft flying parabolic curves to achieve near-zero gravity for 30 to 45 seconds. At right, Deere technicians aboard a NASA research transport are conducting an experimental "pour" of a molten iron sample during a moment of microgravity, their feet strapped to the deck to keep them from floating. The results of a number of such tests prompted Deere to conclude a memorandum of understanding with NASA that is expected to lead to Shuttle-based metallurgical experiments of longer duration.



Although orbital materials processing is still in its infancy, NASA is already cooperating with a dozen companies, under various types of agreements (see page 120), in ground-based and Shuttle-based experimental projects. A larger number of other companies have indicated interest.



Materials Processing Systems

While some companies are focusing attention on materials processing experiments expected to lead to orbital product manufacture, another group of companies is pursuing a different but related line of commercial space development: fabrication of processing systems and equipment for lease to experimenters.

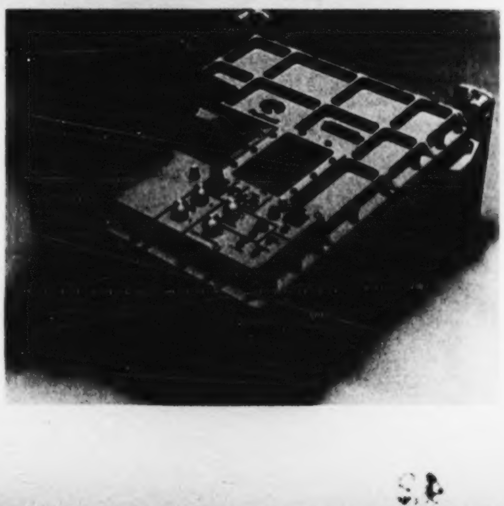
One such system is the Industrial Space Facility (ISF), being developed by Space Industries, Inc., a company formed only three years ago to pursue commercial space ventures. Shown in cutaway view at left, the ISF in its basic form is a large, solar-powered module (35 feet long and 14½ feet in diameter) intended primarily for experimental or operational materials processing in such areas as advanced pharmaceuticals; growing large, ultrapure semiconductor crystals; containerless processing of vastly improved fiber optics; or creation of metal alloys and composites not producible on Earth. The ISF can also serve as a scientific laboratory or as a technology development facility for testing new space equipment and procedures. As many as six modules, each with its own laboratory/factory equipment plus

power storage, temperature control, communications, data management and other provisions, can be docked together to create what the developers call a "space industrial park." The photo at bottom left shows two models of the system mated.

The ISF is designed as an unmanned automated station, but a unique aspect of the design is provision for 2,500 square feet of pressurized volume in each facility module. Thus, Shuttle-delivered servicing crews will be able to work in a shirtsleeve environment for the two or three days it might take for repairs or adjustments, equipment changeouts, product harvesting and cleaning/restocking production apparatus.

In a Shuttle/ISF resupply and servicing operation, the Shuttle Orbiter is docked to the ISF by means of a berthing adapter. Astronauts enter the pressurized part of the facility module through a docking tunnel. Connected to the facility module is a separable supply module containing oxygen for pressurization and other consumables; resupply modules, six to 11 feet long, will be Shuttle-delivered every three to four months and depleted modules returned to Earth. The periodically man-tended ISF will operate in the same orbit as that of the planned Space Station and it will also be able to dock with the Space Station for servicing.

By agreement, NASA and Space Industries will exchange non-proprietary data and work together on technical matters and operational support requirements. Space Industries has completed preliminary engineering, applied for patents, begun negotiations with equipment suppliers and awarded a contract to Lockheed Missiles & Space Company for the large solar array. Target date for operational service of the first ISF is 1989.



At left below is another type of space platform intended primarily to support materials processing payloads. Called Leasecraft, it is being developed under a Joint Endeavor Agreement with NASA by Fairchild Space Company for debut in 1988.

The Leasecraft platform will measure 15 by 15 by 14½ feet and it will be equipped with modules supplying power, command, data handling and other utilities required by payload modules, which will be mated to the platform in orbit. Platforms will be launched from the Space Shuttle; the Shuttle Orbiter will rendezvous with them about once every six months to exchange new materials for finished products in manufacturing operations, or to change scientific or remote sensing instrument packages. NASA will support Leasecraft flights through Goddard Space Flight Center's control facilities.

Along with these free flying platforms, both government and industry are developing a number of laboratory systems for materials processing experiments, usually small, compact equipment that can be accommodated in minimal space aboard the Shuttle Orbiter, the Space Station or facilities like ISF and Leasecraft. Marshall Space Flight Center (MSFC) leads in development of this type of equipment; MSFC has built such systems as the Monodisperse Latex Reactor (see page 36), furnaces for melting and solidifying materials in microgravity and camera-equipped systems for studying separation of materials under weightlessness. Both MSFC and Jet Propulsion Laboratory have developed "acoustic levitators" for containerless processing of materials floating in a chamber, manipulated by acoustic energy.

Private companies are also entering this field of space commercialization, developing laboratory facilities for lease to research institutions and commercial experimenters. An example is the Zero G Laboratory, also known as the Fluids Experiment Apparatus (FEA), developed by Rockwell International's Space Transportation Systems Division. Shown at left, the FEA was introduced to space service when it flew aboard a 1984 Shuttle mission (see page 14).

The FEA is designed to handle a range of processing applications, including liquid chemistry, fluid physics, thermodynamics, crystal growth and biological cell culturing. About the size of a 19-inch television, it has the functional capability to heat, cool, expose to vacuum and manipulate experiment samples, which may be gaseous, liquid or solid. Samples may be removed or changed during a mission and a video camera may be installed to record sample behavior and instrument data displays.

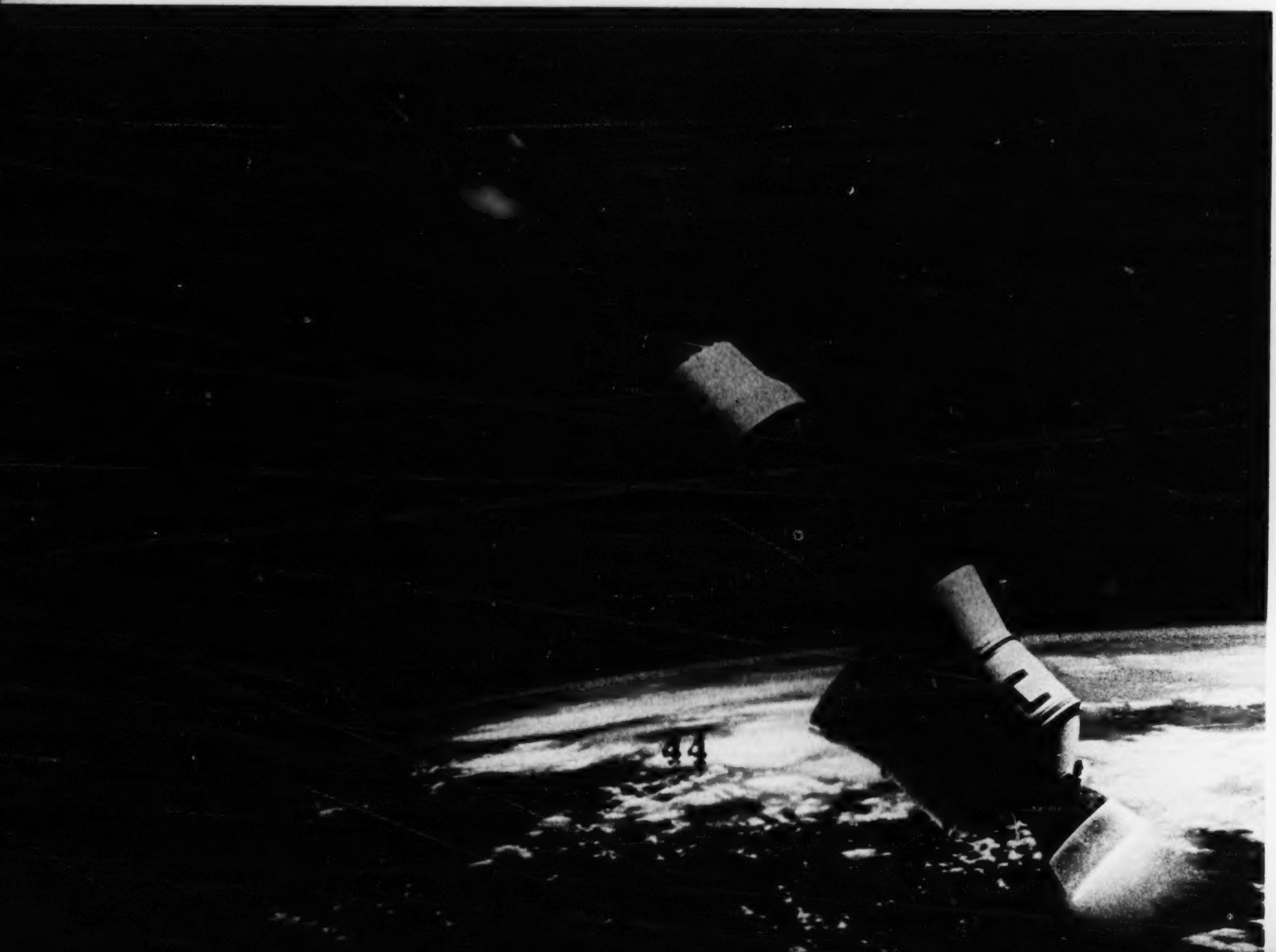
Upper Stage

Shuttle delivery of spacecraft intended for operation in high altitude Earth orbit or in interplanetary trajectory is a two-step process. The payload is first deployed from the Shuttle Orbiter in low Earth orbit, then transferred to its requisite orbit by a secondary boost from an upper stage launch system affixed to the payload.

A new medium capacity upper stage is under development as a commercial enterprise in cooperation with NASA. Known as the Transfer Orbit Stage (TOS), it is being developed by Orbital Sciences Corporation (OSC) with private capital. NASA is not contributing any direct financial support but provides technical monitoring of TOS progress through a project office at Marshall Space Flight Center. This arrangement will make a new space transportation system available for government as well as commercial service while saving the government the estimated $50 million required to develop the system.

TOS is being built by Martin Marietta Denver Aerospace, prime contractor to OSC. Powered by a solid propellant rocket motor, TOS is being developed under a design philosophy that combines extensive use of space-qualified hardware with selective application of new technologies. The stage is expected to be ready for service by late 1986.

OSC and Martin Marietta are also developing a complementary upper stage called the Apogee and Maneuvering Stage (AMS), which employs space-storable liquid rocket technology. Used as a combined two-stage vehicle, the TOS/AMS can deliver a 6,500-pound payload to geosynchronous orbit, an altitude of 22,300 miles where all commercial communications satellites and some other space systems operate. On such missions, the TOS stage delivers a high-thrust, short-duration injection into elliptical transfer orbit; the AMS provides insertion into circular orbit and precise final positioning of the payload. The accompanying illustration shows AMS boosting a large satellite following separation of the TOS stage. TOS/AMS is targeted for initial service availability in December 1987.



Technology Twice Used

Much of the technology developed for NASA's mainline programs is being adapted by private firms and public sector organizations for secondary use in a broad range of new products and processes that are providing important economic and social benefits

Spinoff developments highlighted in this section are based on information provided by secondary users of aerospace technology, individuals and manufacturers who acknowledge that aerospace technology contributed wholly or in part to development of the product or process described. Publication herein does not constitute NASA endorsement of the product or process, nor confirmation of manufacturers' performance claims related to the particular spinoff development

A family of highly advanced pressure sensing systems exemplifies the benefit potential of aerospace technology transfer

Spinoff from Wind Tunnel Technology

Last spring, Pressure Systems Incorporated (PSI) dedicated a new, million-dollar plant and headquarters in Hampton, Virginia, a major milestone in the company's short but active history. PSI began life—in 1977—in a single room of the home of its president and founder, former NASA instrument design engineer Douglas B. Juanarena. A year later, the firm started deliveries of its initial product and in 1979 expanded into a 5,000 square foot facility in Hampton. The new plant offers three times as much floor space and from all indications PSI will need every inch of it; in the short span of eight years, the company has become one of the world's leading suppliers of electronic pressure scanning equipment.

PSI is an aerospace spinoff company whose product line originated in work at Langley Research Center in the early 1970s. Langley was looking for a way to obtain better accuracy and higher data rates in measuring airflow pressures at a great many points in a wind tunnel model. Mechanical systems then in use had a maximum capability of 10 measurements a second. That required long and repetitive tunnel runs to accomplish the hundreds of measurements needed in a typical test program; additionally, inaccuracies were induced because test conditions changed over the lengthy period necessary to make the measurements. There was a corollary need to cut energy costs, which were then soaring as a result of the world energy crisis. Since wind tunnels consume enormous amounts of energy, it became imperative to find means of shortening tunnel operating times without compromising data accuracy or quantity.

Langley found a solution to both problems in a new technology known as electronically scanned pressure (ESP), developed by a team that included engineers Douglas Juanarena, Thaddeus Basta Jr., George Walker and the project's chief, Chris Gross. The Langley ESP measurement system was based on miniature integrated circuit pressure-sensing transducers that communicated pressure information to a minicomputer; these sensors were capable of being calibrated while in use, an innovation that greatly improved accuracy. High data

Above, a Space Shuttle Orbiter model is undergoing wind tunnel test at Langley Research Center. Tests like this require hundreds of measurements of pressure distributions on the model. Langley's problem, in the early 1970s, was that mechanical pressure-sensing methods provided only five to 10 measurements a second, necessitating long and expensive test runs. The answer was a new Langley-developed technology that allowed extremely high measurement rates; since translated into a commercial product line marketed by Pressure Systems Incorporated (PSI), it is known as electronically scanned pressure.

rate was achieved by using one transducer for each pressure port in a wind tunnel, a development that would have been impractical with mechanical systems because of size and cost considerations. Inherent errors in the transducers were automatically corrected by a microprocessor. The basic system, developed over several years, was a module with 48 transducers—or channels—capable of making 1,000 measurements a second, a hundredfold improvement. In addition, the module was small in size, relatively low in cost, highly accurate and more reliable than predecessor systems, in all a major advance in pressure-sensing technology.

In 1978, Douglas Juanarena obtained a license to manufacture and market products based on the NASA-patented technology, resigned his Langley position and founded PSI. He was subsequently joined by the other members of the ESP development team. Chris Gross is now PSI's executive vice president, George Walker is vice president for production and Thaddeus Basta is chief systems engineer.

PSI continued to develop the technology and now produces ESP modules and accessories in 16, 32 and 48 channel configurations, with data rates up to 20,000 measurements a second, for use in wind tunnels and engine test stands, and for in-flight pressure measurements in aircraft. Customers include U.S. and foreign government research centers and major aerospace companies, who operate their own wind tunnels and engine test facilities. PSI found a secondary market in the auto industry. Automakers, particularly European firms, are becoming increasingly interested in reducing aerodynamic drag and they are using pressure sensors in wind tunnel and test track research. Users of PSI equipment include Mercedes-Benz, Porsche and Volkswagen.

Looking to the broader potential of ESP technology, PSI developed an industrial pressure scanner for automation of industrial processes where there is need for making multiple pressure measurements quickly and with high accuracy. Capable of making up to 2,000 measurements a second, the company's DPT 6400 module has 64 channels but the system can be expanded to 256 channels by addition of "slave" units. Relatively new, the DPT 6400 has already found a place in the industrial market with applications in a number of process plants and refineries. For example, Eastman Kodak Company, Rochester, New York, uses the system to monitor pressures in an emulsion process wherein even distribution of pressure is important while applying coating to film; Formica Corporation, Evendale, Ohio uses ESP modules to calculate the flow rate of fiber blown through ducts; Huntington Alloy, Huntington, West Virginia, monitoring fuel consumption in natural gas furnaces, employs PSI equipment to determine the gas flow rate.

PSI's product line now embraces 10 basic pressure measurement systems plus a variety of ancillary instruments and accessories. Sales reached the million-dollar level by 1981 and in 1985 they are expected to top $2.5 million. Company officials forecast substantial growth over the next five years, particularly through the DPT 6400, a valuable aid to automating industrial process plants.

The entire PSI product line stemmed from the original ESP work at Langley, a fact that points up the economic potential of spinoff. As happens frequently, a technology transfer resulted in establishment of a thriving new company, with attendant benefit to the nation's Gross National Product and to job creation. Spinoffs whose benefits are valued in the millions of dollars—such as PSI—are not unusual. In other cases, spinoffs generate only moderate economic gain but provide significant public benefit in other ways, ranging from simple conveniences to important developments in medical and industrial technology.

For the past 23 years, under its Technology Utilization Program, NASA has been actively engaged in encouraging the secondary application of aerospace technology. During that time, literally thousands of aerospace originated innovations have found their way into everyday use. Collectively, these spinoffs represent a substantial return on the aerospace research investment in terms of economic gain, improved industrial efficiency and productivity, lifestyle enhancement and solutions to problems of public concern.

Above, a technician is monitoring a PSI pressure scanner. Shown below is the company's latest system, the DPT 6400, designed to permit up to 2,000 measurements a second in industrial process applications.

Fabric roofing for retail centers highlights a selection of spinoffs in the field of construction

A New Look for the Shopping Mall

Opened last year, the East Towne Mall in Knoxville, Tennessee exemplifies a growing trend toward covering retail centers—wholly or partially—with permanent architectural fabric. The fabric used in construction of East Towne Mall is STRUCTO-FAB®, a product of Owens-Corning Fiberglas Corporation, Toledo, Ohio, a lightweight but extremely durable material made of Fiberglas® coated with Teflon®. The translucent STRUCTO-FAB roofing transmits daylight to create a bright, outdoors-like atmosphere with reduced need for artificial lighting, thus providing not only an aesthetically-appealing structure but also an energy-efficient enclosure for protection from the weather.

The focal point of East Towne Mall is the large Center Court, whose lofty STRUCTO-FAB roof measures more than 15,000 square feet. The Center Court contains a two-story atrium, a food pavilion with more than a dozen restaurants sharing a common dining area, and a stage for such events as fashion shows and musical performances. One of the architectural attractions of STRUCTO-FAB is that the fabric structure requires fewer interior supports than conventional roofs, thus freeing more floor space for use. The Center Court is supported by only three 64-foot steel masts.

In addition to the Center Court, there are two intermediate courts, each covered by 2,700 square feet of STRUCTO-FAB supported by six laminated wood arches. There is also an 1,800-square-feet fabric

entrance canopy. Owens-Corning's Fabric Structures Division was design/build contractor for the fabric-covered areas of East Towne Mall, which is a joint venture of Melvin Simon & Associates of Indianapolis and JCP Realty of New York City. The architectural design company was Copeland, Novak, Israel and Simmons, also of New York.

John McNamara, senior vice president of the latter firm, explained why STRUCTO-FAB was selected: "The fabric structure seemed very appropriate. We needed large, unobstructed spans for the court areas and we also wanted a change in character to break up the long travel distances in the center. The cheerful ambience of the 'tents' seemed just right, especially for the Center Court."

STRUCTO-FAB is an outgrowth of a material whose origin dates to 1967, when NASA was looking for a new fabric for astronaut space suits. It had to be durable and noncombustible, yet thin, light and flexible. Owens-Corning had been experimenting with a glass fiber yarn that seemed to meet all the requirements. The yarn was woven into a fabric, coated with Teflon (a product of The Du Pont Company, Wilmington, Delaware) and tailored for astronaut wear. The material thus produced provided the basis for development of heavier, construction-use adaptations.

At East Towne Mall, the fabric transmits 10 percent of daylight, but STRUCTO-FAB can be engineered for other applications to translucence values ranging from four to 18 percent. Because the filtered natural light is diffuse, shadows and glare disappear. In addition to the lessened need for artificial lighting, the fabric's high reflectivity—about 75 percent—minimizes solar heat buildup, contributing to lower cooling costs. Pound for pound, the Fiberglas fabric is stronger than steel; it weighs less than five ounces per square foot. STRUCTO-FAB has a number of attributes that combine to reduce maintenance requirements: the Teflon coating makes the fabric resistant to moisture, temperature extremes and deterioration, and the non-stick characteristics of Teflon allow periodic cleansing of the roof surfaces by rainfall.

STRUCTO-FAB has been used to cover a number of other malls and retail centers in recent years. The first—in 1982—was the award winning Mall At 163rd Street, Miami, Florida. Other examples include the Buenaventura Mall, Ventura, California, completed last year; Bullock's Fashion Island, San Mateo, California; Town & Country Mall, Houston, Texas; and Crossgates Mall, Albany, New York. Although mall-covering is a relatively new application, Fiberglas fabric as a permanent covering has been in service since the early 1970s in a wide variety of structures all over the world, among them the Haj Terminal at King Abdulaziz International Airport, Jedda, Saudi Arabia; animal enclosures at the North Carolina Zoological Park (Asheboro) and Boston's Franklin Park Zoo; and many sports and recreation centers, such as the Pontiac (Michigan) Silverdome and the Stadium at B.C. Place, Vancouver, British Columbia.

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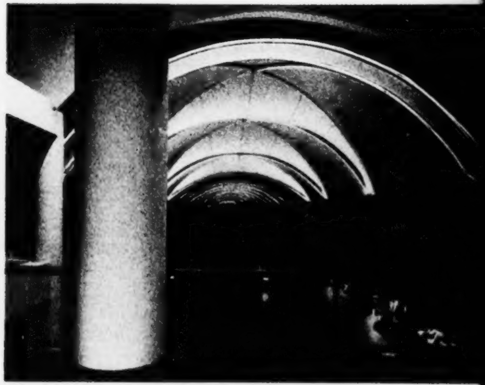
®Teflon is a registered trademark of The Du Pont Company.



At left, translucent covering of the Center Court at East Towne Mall, Knoxville, Tennessee admits daylight to provide an outdoors-like atmosphere.

Fabric roofing speeds construction, lowers costs and inspires innovative designs, such as the "caravanserai look" of Bullock's department store, San Mateo, California shown above.

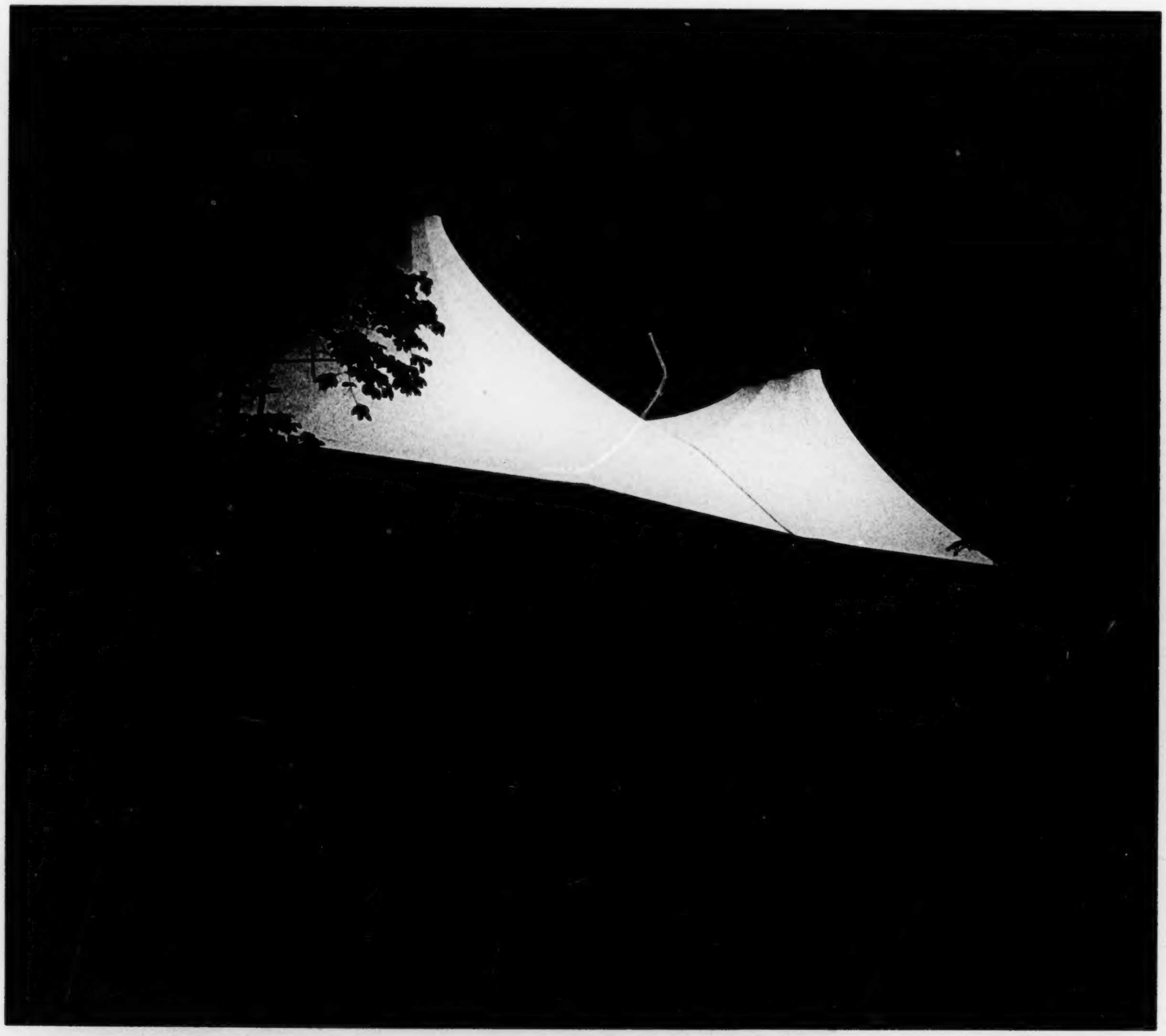
The trend-setting Mall At 163rd Street, Miami, Florida, was the first shopping center to be completely enclosed by a permanent Fiberglas fabric roof. In this nighttime view, the roofing material reflects and diffuses interior lighting to provide soft, glareless illumination.

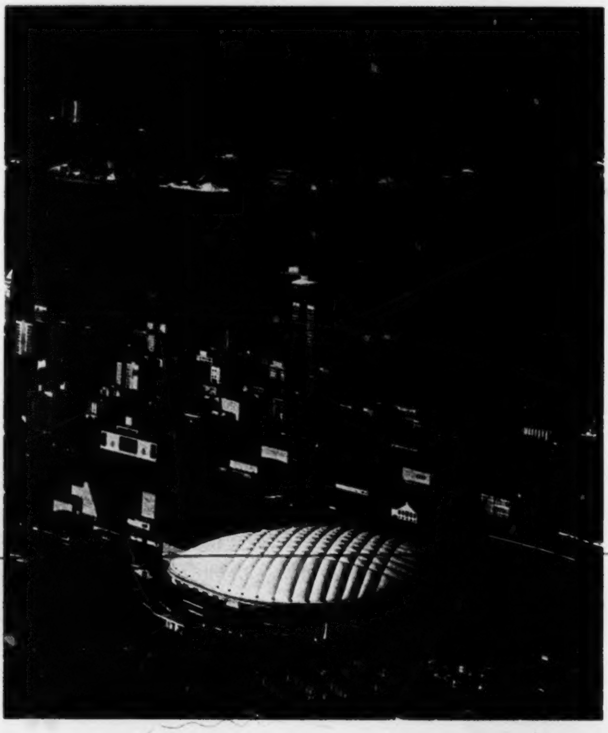
Other Fabric Structures

Architects, engineers and building owners are turning increasingly to fabric structures because of their aesthetic appeal, relatively low initial cost, low maintenance outlays, energy efficiency and good space utilization. Fabric structures are built in two basic ways: some are tension structures supported by a network of cables and pylons, others are supported by air pressure within an enclosed fabric envelope. The photos on these pages exemplify one structure of each type whose roof is made of Owens-Corning's STRUCTO-FAB Fiberglas fabric.

The photos below and at upper right show exterior and interior views of the African Pavilion at the North Carolina Zoological Park in Asheboro, a tension structure. The recently completed pavilion will be home to more than 200 animals representing 25 species. It also houses native African plants; the translucent fabric transmits sufficient natural light to sustain plant life. The STRUCTO-FAB roof encloses four distinct animal habitats in a single 46,000 square foot structure.

The photo at far right shows the air-supported Stadium at B.C. Place, Vancouver, British Columbia, Canada's first covered stadium. Seating up to 60,000, the stadium is a multipurpose sports area, exhibition center, convention facility, concert hall and entertainment amphitheater. The 10-acre STRUCTO-FAB roof, shown at right below during the construction phase, weighs only 1/30th as much as a conventional roof of that size. Sixteen giant fans blow air into the balloon-like envelope between the roof's outer membrane and its inner liner, automatically maintaining the pressure differential necessary for roof rigidity.





Power Plant Construction

Stone & Webster Engineering Corporation, Boston, Massachusetts provides engineering services to the power plant and process industries in the U.S. and abroad, including design, construction and consulting work on coal-powered, hydroelectric and nuclear power plants. The accompanying photos picture construction of a nuclear power plant at Millstone, Connecticut, one of several nuclear facilities designed by Stone & Webster with the aid of a NASA-developed computer program.

One phase in the design of a nuclear power plant involves computer analyses to qualify safety-related equipment at the temperatures it would experience should an accident occur. For such analyses, Stone & Webster uses a program called TAP-A (Computing Transient or Steady State Temperature Distribution). TAP-A was originally developed as part of a NASA investigation into the potential of nuclear power for space launch vehicles. Stone & Webster reports that the company selected TAP-A because it is relatively easy to use, produces accurate results and is not expensive to run.

Stone & Webster's use of TAP-A exemplifies a NASA service to industry provided by the Computer Software Management and Information Center (COSMIC)®, located at the University of Georgia. COSMIC supplies computer programs, originally developed by NASA and other technology-generating agencies of the government, that can be adapted to secondary usage; thus, business and industrial customers of COSMIC can save the time and expense of developing entirely new software.

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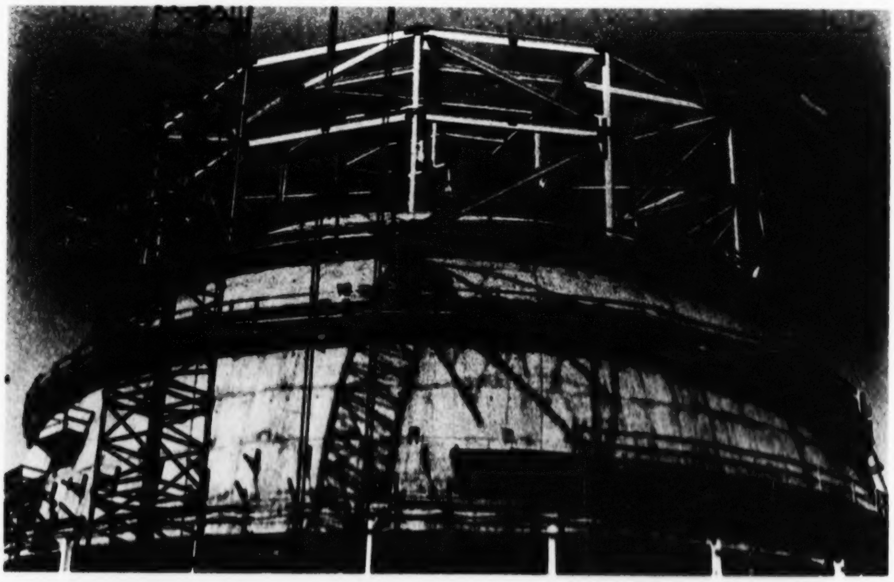
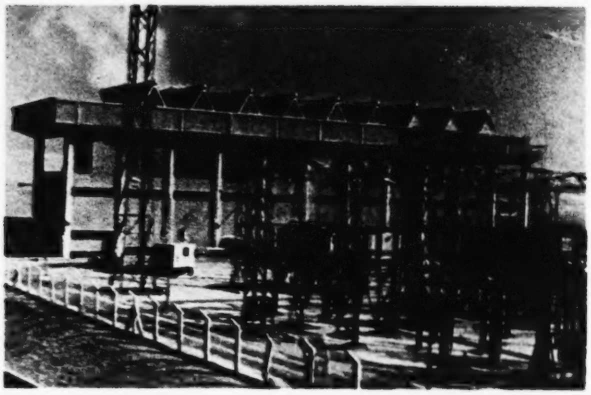




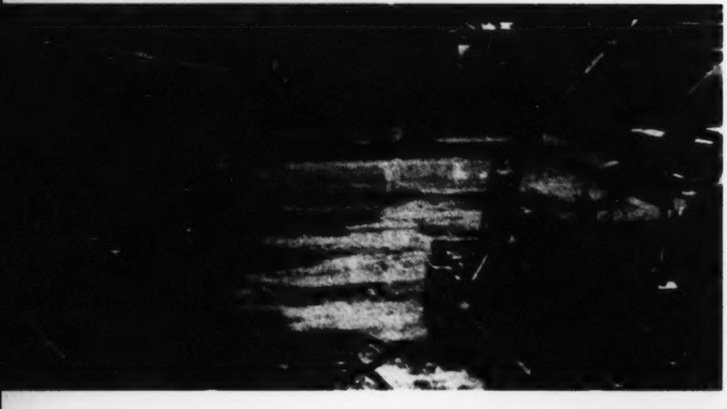
Power Station Design

Based in Philadelphia, Pennsylvania, Kuljian Corporation provides planning, design, engineering and construction management services, specializing in the design and construction of power generating plants, desalination/power complexes and power transmission systems. The accompanying photos are representative of some 200 power generation plants in more than 20 countries that bear the Kuljian name.

At left is the 66 megawatt Hussein Station at Zerqa, Jordan; shown below is Mooreland Station, Mooreland, Oklahoma, a 148 megawatt unit designed for the Western Farmers Electric Cooperative.

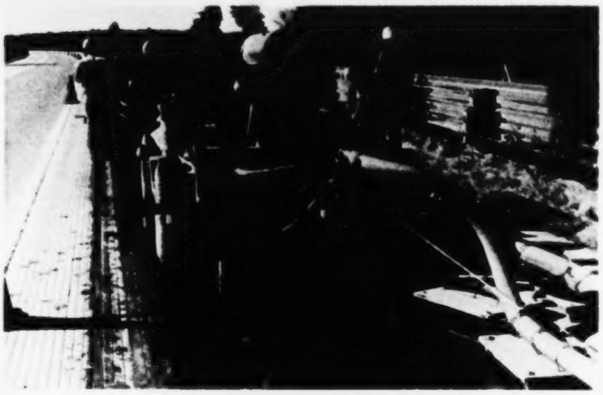
Among the company's most recent projects are two 500 megawatt steam power plants in Singrauli, India. In the course of designing these units, Kuljian engineers used a NASA-developed computer program supplied by the Computer Software Management and Information Center (COSMIC), NASA's software dissemination facility, which routinely supplies to industry government-developed computer programs that have secondary utility. The program—WASP (Calculating Water and Steam Properties)—was used by Kuljian to optimize the design of the power station, with special emphasis on heat balance in the steam turbine cycles. Similar applications are foreseen in optimizing the thermal design of other Kuljian engineered large power generating units. The company reports that availability of the WASP program allowed substantial reductions in the lead time and cost of software required for the Singrauli design project.

Safety Grooving



At left, a machine equipped with diamond blades is cutting grooves in the concrete holding pen of a California cattle ranch as an animal safety measure. Concrete surfaces are regularly employed for sanitary purposes in pen and feeding areas, but in time the surface finish wears smooth and becomes slippery. This gives rise to the danger that valuable cattle may fall and be seriously injured or killed; it happens often enough to pose a major problem for cattle ranchers and dairy farmers. Operators of such facilities, in the U.S. and abroad, have found safety grooving an effective remedy.

This rather unusual use of safety grooving exemplifies a rapidly expanding list of new applications for a spinoff technique originally



developed more than two decades ago. Most new applications are intended to prevent injury to humans rather than animals. Concerned about traction problems on wet and slippery surfaces, safety engineers are increasingly specifying grooving or texturing—a related process that creates a rough, sandpaper-like surface—in construction plans for new or renovated facilities.

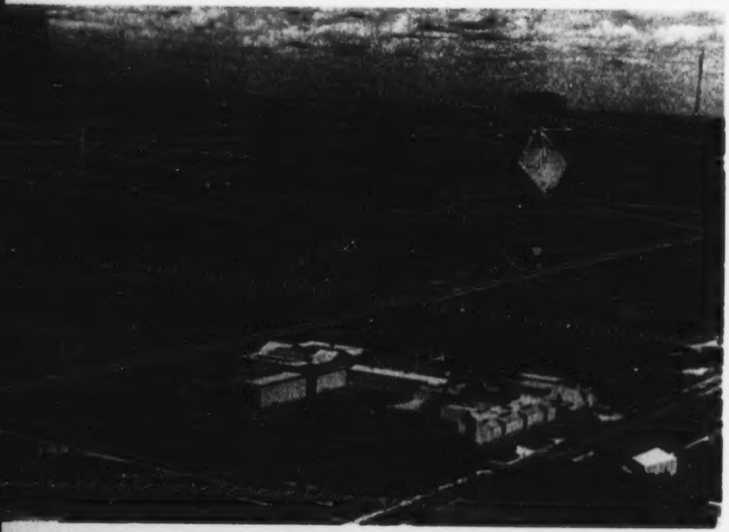
Safety grooving to improve human and animal footing on slick or smooth surfaces represents a "spinoff from a spinoff." The technique was first developed to reduce aircraft accidents on wet runways and was subsequently widely adopted as a highway safety measure. Grooving commercial airports, which began in the 1960s, helped launch the grooving industry in the U.S. That industry—represented by the International Grooving & Grinding Association (IG&GA), New York City—expanded considerably when safety grooving gained acceptance among highway engineers. Over the past five years, pedestrian safety applications have contributed to further growth of the industry. IG&GA now has a membership, consisting of grooving contractors and manufacturers of grooving equipment, that embraces more than 30 companies in the U.S. and in Europe, Australia and Japan.

In the early 1960s, NASA's Langley Research Center began an extensive research program that led to the type of remedial grooving currently employed on airport runways around the world. The technique was designed to curb skid-causing "tire hydroplaning," a condition that occurs during rainstorms when tires rolling or sliding along a water-covered pavement are lifted away from the surface by the action of water pressure. In other words, the tire is riding on a film of water that separates the tire tread from the surface. The grooves, cut transversely across the runway, create channels through which excess water is forced, thereby reducing the skid hazard and increasing an airplane's braking effectiveness.

Langley Research Center demonstrated its corrective technique and assisted the Federal Aviation Administration in testing the efficacy of various groove configurations. This led to the first runway grooving at a U.S. commercial airport—Washington (D.C.) National Airport—in 1967. Since then hundreds of military and civil airports have been safety-grooved in the U.S., Canada, Europe and Asia. The process is typified in the bottom photo, opposite page which shows a runway being grooved at Daytona (Florida) Airport. In a survey of U.S. airport managers conducted by IG&GA, 91 percent of the respondents said they would recommend runway grooving as a valuable maintenance/safety improvement.

Langley scientists were also instrumental in bringing the problem and its solution to the attention of highway safety engineers and highway grooving began in the U.S. at about the same time as runway grooving. Generally, highways are grooved longitudinally—along the line of vehicle movement—rather than transversely, because transverse grooving takes longer and necessitates closing highways for longer periods. The result, however, is about the same: it reduces skidding, decreases stopping distances and increases a vehicle's cornering ability on curves. A report by the California Division of Highways, which made before-and-after grooving studies at 14 locations, showed an after-grooving wet weather accident reduction of approximately 85 percent. Highways have been grooved in many U.S. states and in a number of countries in Europe and Asia; the middle photo, opposite page shows a grooving machine cutting longitudinal channels in a section of Japan's Tohoku Expressway.

In the last five years, the success of runway/highway safety grooving has inspired a wide range of new applications and caused the members of the IG&GA to develop new types of diamond-bladed grooving machines, smaller and lighter because they must be operated on narrower surfaces and maneuvered in tight quarters. An example is the machine being used at left, where the granite steps of a Philadelphia school are being grooved to keep students from slipping and falling in wet weather. Among other examples of grooving outdoor surfaces for pedestrian safety are sidewalks, playgrounds, parking lots, service stations, car washes, railroad station platforms and swimming pool decks. Indoor grooving examples include the slippery-when-wet entrance to a West Coast bottling plant (above) and occasionally slick working areas in refineries, factories, warehouses, meat packing facilities and food processing plants.



Aerial Photography

The accompanying photos exemplify the work of photographer John Hill, who operates Tigerhill Studio, Western Springs, Illinois. Hill, a licensed commercial pilot with a civil engineering degree and military experience in photo interpretation, began the business in 1982 after more than 20 years in construction management. He specializes in high quality oblique aerial photography, supplying three-dimensional frontal photos for such clients as real estate developers, architects, advertising agencies, government agencies, hotel and resort operators, oil companies, museums and Chambers of Commerce.

At upper left is an oblique view of the Art Institute/ Michigan Avenue area of Chicago, Illinois. At left is an aerial view of Jefferson Mall, Yorktown, New York, taken on an assignment flown for the developer and general contractor. The bottom photo pictures a segment of Washington, D.C. along the Potomac River. At right is the Chicago Loop skyline and at right below is the G.D. Searle headquarters building in Skokie, Illinois. Hill says the latter two photos illustrate the quality that can be attained on a hazy day with the right camera and proper film; he credits a NASA Industrial Applications Center with an assist in reducing his operating costs and in his selection of cameras, lenses and films for the demanding field he chose to enter.

In preparing his business plan for entering this highly specialized field, Hill—aware of many NASA advances in photography, remote sensing and computerized image enhancement—sought to build an information base on space age technology related to his work. He found the information available in libraries limited and often outdated, so he contacted—

through the Small Business Administration office in Chicago—the New England Research Applications Center (NERAC), Storrs, Connecticut, a data retrieval service jointly sponsored by NASA and the University of Connecticut. Hill asked NERAC to conduct a literature search to identify the latest developments in a range of subjects relating to camera optics and performance.

NERAC searched the NASA data base and provided extensive information on aerial, aerial oblique and architectural photography, electro-optics, image enhancement and processing. Hill followed up the NERAC report through personal contacts with manufacturers of photographic equipment and film, aerial surveyors, processing laboratories and camera retailers. As a result of this cooperative research effort, Hill was able to effect an immediate and substantial reduction in overhead costs. Much of the saving stemmed from his switch from a heavy military aerial camera to a lighter weight, more manageable camera that makes sharper pictures and can be used in a small fixed-wing airplane as well as in more costly helicopters. Additionally, he is using NERAC-provided information on electro-optics, image enhancement, microwave and infrared systems to plan for his introduction of advanced optics. Hill estimated that NERAC's assistance will contribute to an increase of about $100,000 in 1984/85 revenues and significantly strengthen his competitive position for future work.

Architectural Panels

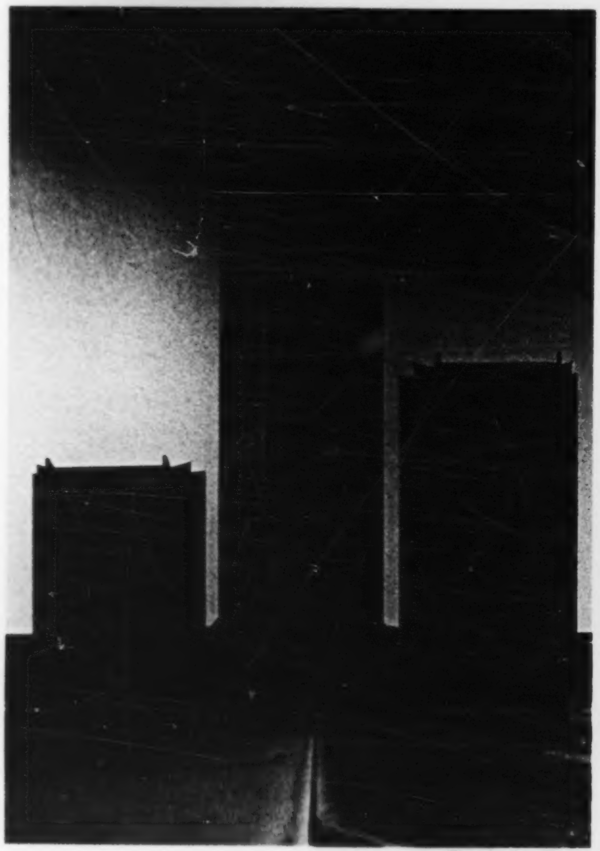


Photo by Don Klumpp

In the upper photos, youngsters are daubing paint and affixing magnetic shapes to their schoolroom wall at a Kinder Care Learning Center. But the wall panels will suffer no damage. They are Whyteboard porcelain enamel on steel panels, manufactured by AllianceWall® Corporation, Okmulgee, Oklahoma. Removal of the magnetic figures will not scar the panels and the paint can be removed without a trace by a wipe of a damp cloth. This feature of Whyteboard, allowing children to write, paint, draw and clip on the walls, gave Kinder Care centers a new dimension. It was, however, just one of several reasons why Kinder Care, the largest preschool child care organization in the U.S., decided to use Whyteboard in its centers.

Kinder Care faced a problem of very high maintenance costs at the centers, due to frequent need for new paint and wallpaper. Construction managers sought a better interior material for building new centers and remodeling old ones, an economical material that would require little maintenance yet would meet the varying local, state and regional fire codes. They found it in AllianceWall's Whyteboard, which eliminates painting and wallpapering and is virtually maintenance free, capable of resisting scratches, smudges, stains and fading of its hard-as-glass surface. Kinder Care has specified Whyteboard for all its new centers and for selected remodeling projects.

Whyteboard is one of a number of types of panels manufactured by AllianceWall, the world's largest producer of architectural porcelain on metal. In

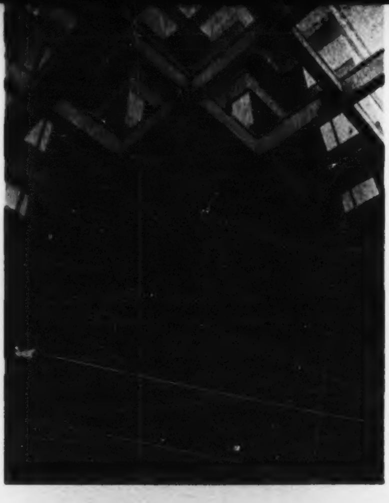
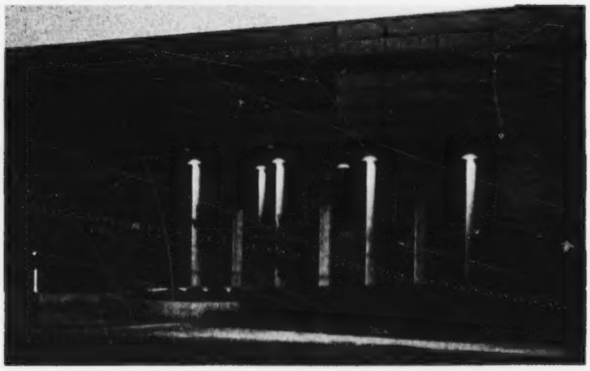


Photo by Rabbit Hare, Tulsa World



addition to interior panels, widely used in such applications as classrooms, offices, conference rooms and corridors, the company supplies a variety of exterior porcelain enamel on steel products that offer similar advantages: no chipping, scratching, heat blistering; colors won't corrode, oxidize or fade, so refinishing is never needed; graffiti and other blemishes can be easily wiped off with solvents or paint removers without harm to the surface.

Some examples of exterior applications are shown in the accompanying photos. At left, 225,000 square feet of AllianceWall porcelain-enameled steel provide a maintenance-free exterior for the City of Faith Medical and Research Center on the campus of Oral Roberts University, Tulsa, Oklahoma. At left top, AllianceWall panels enhance the unusual design of the 4040 Broadway Building, San Antonio, Texas. Below it is the Paragon Building, Houston, Texas and at right above is Wayne County Community College, Detroit, Michigan.

Among the factors that have won AllianceWall a worldwide customer base are the wide range of colors available and the color stability maintained in the enameling process. Through Kerr Industrial Applications Center (KIAC), NASA provided assistance that helped AllianceWall improve its color stability. Located on the campus of Southeastern Oklahoma State University, KIAC is one of 10 NASA sponsored dissemination centers that provide information and technical help to industrial and government clients.

In the AllianceWall enameling process, finely milled glass frit is combined with various oxides to give the desired color and texture to the porcelain enamel surface, which is guaranteed to resist color fading and is virtually unaffected by ultraviolet rays, acid rain or weather. To maintain color stability, AllianceWall wanted to improve on its visual methods of detecting flaws, matching colors and measuring gloss; the company sought an advanced method of detecting color/gloss changes and establishing quantitative tolerances. AllianceWall asked KIAC to conduct a worldwide engineering background study to identify potential technologies and manufacturers of equipment that could be used to detect surface flaws, color and gloss changes on enameled surfaces.

KIAC ran computer searches of three data bases, including NASA's, and provided AllianceWall 77 pertinent reports. The information resulted in company purchase of a spectrocolorimeter manufacturered by Hunter Laboratories; above top, AllianceWall's Sue Edmonds displays samples of the color panels and part of the colorimeter system, which can "read" colors from a color chip or continuous strip and provide information for reproducing the exact tone and shade. The equipment enables AllianceWall to control some 250 standard colors and match any special color a customer might want. KIAC also provided information on laser and ultrasonic equipment that can detect surface flaws—such as trash, bubbles or depressions. AllianceWall plans to put such equipment into service for further improvement of its product line.

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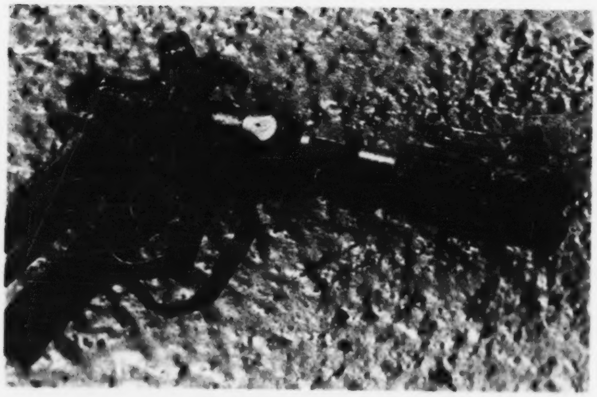
Foam Dispenser



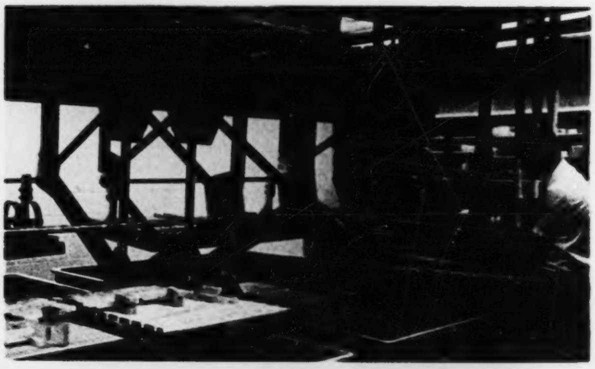
In spraying plastic foam, such as polyurethane used for insulation and soundproofing, the foam's two ingredients, properly proportioned, must be combined just before spraying and they must be fully mixed to insure proper hardening and adherence. William G. Simpson, a NASA employee at Marshall Space Flight Center, invented a mixing device that improves upon other mixers; it provides a more thorough blending of the ingredients and enhances the consistency and uniformity of the sprayed foam. The device is a spray nozzle insert equipped with a series of discs that cause the material to change direction repeatedly, so that they are completely blended by the time they reach the nozzle outlet. The simple construction of the dispenser makes cleaning easy; the nozzle is unscrewed, the insert removed and cleaned, and the mixing chamber flushed out.

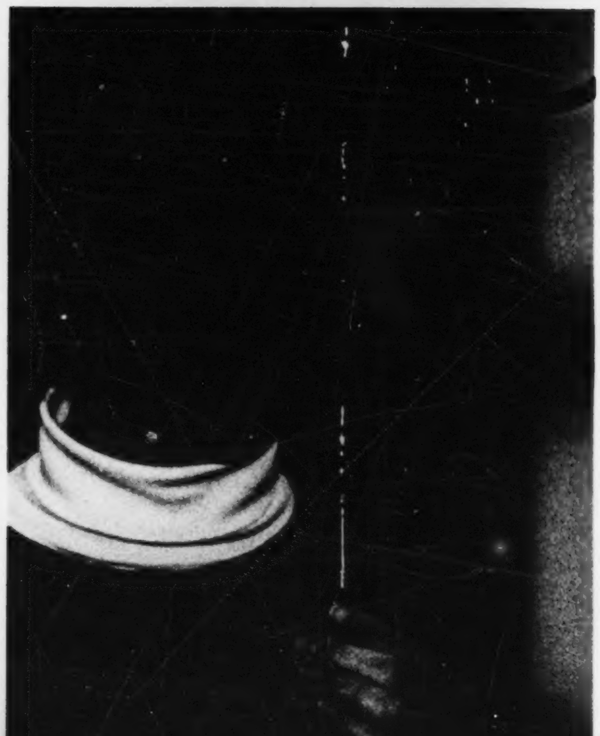
Simpson obtained a patent for the invention and a license to manufacture and market the nozzle, known commercially as the Simpson Mixer; it is pictured (left above) at the tip of a spray gun. Simpson formed a company to sell the device and he is supplying it to a number of foam applicators. One such is Commercial and Industrial Applicators, Inc. (CIA, Inc.) Houston, Texas. CIA, Inc. applies polyurethane foam elastomeric coatings for insulation of tanks, pipelines and roofing systems. At left, a CIA, Inc. technician is using the Simpson Mixer to dispense an elastomeric coating onto the roof of a building at Texas A&M University; the photo below shows the job near completion, with a topping of ceramic granules (red-brown area) over the coating to achieve the aesthetic appearance desired by the university.

Stress Corrosion Testing

Structural materials—for example, the metals used in aircraft, bridges or storage tanks—may develop flaws during their service lifetimes that can affect the structural integrity of a component. Thus, it is important to know the fracture toughness of a material, or its ability to resist cracks.

NASA has had long experience in developing tests to determine the fracture toughness of materials used in aerospace hardware. Lewis Research Center and Langley Research Center, working closely with the American Society for Testing and Materials (ASTM), have made a number of important contributions to the science of predicting materials behavior. Advanced test procedures developed by the two NASA centers and their contractors have been accepted and recommended by ASTM, to the benefit of the entire materials and structure evaluation industry.

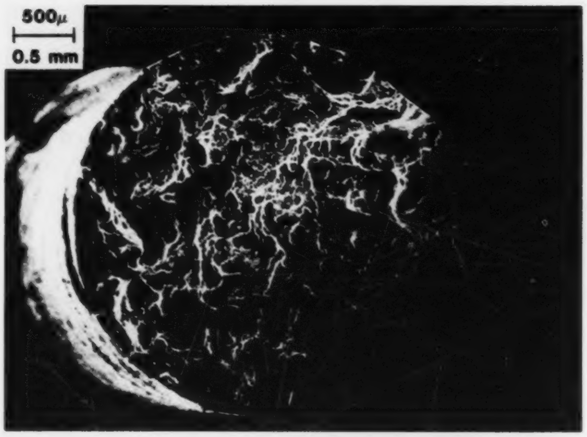




A recent effort in this area is a study conducted by Aluminum Company of America, Alcoa Center, Pennsylvania. Under contract to Langley, Alcoa Laboratories researched state-of-the-art methods for evaluating stress corrosion cracking, a process involving the interaction—over time—of tension stress and a corroding substance at a metal surface. Dealing with stress corrosion cracking problems is a costly matter to industry; proper selection of engineering material is an important first step in avoiding stress corrosion failures.

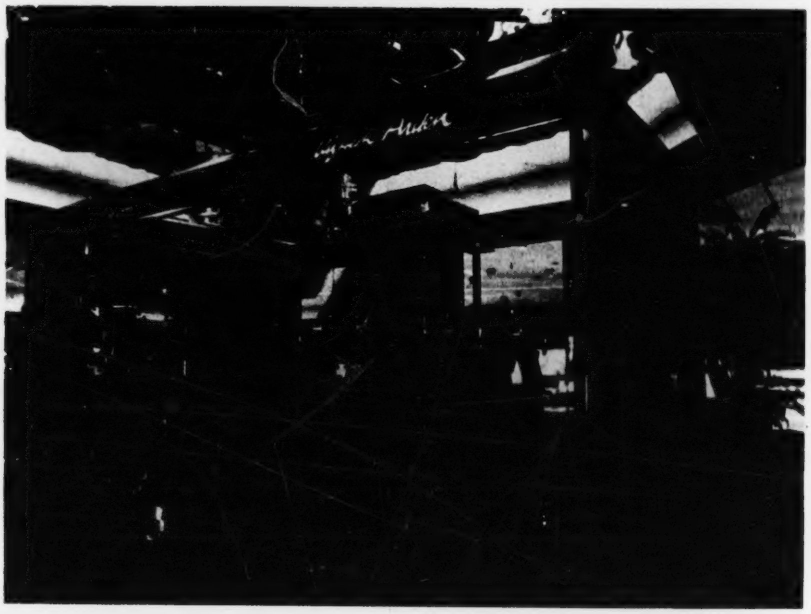
After three years of research concluded last year, the study recommended as the optimum test procedure a technique known as the "breaking load" method. Developed by Alcoa, this new method determines fracture strengths by loading cylindrical test bars until they fail, after the bars have been exposed to a corrosive environment in the presence of a sustained stress. In the Alcoa procedure, a test specimen—mounted in a self-stressing frame—is placed on a movable rack that is periodically lowered into a tank containing sodium chloride solution (left). After exposure to this corrosive environment for a period of four to 10 days, the specimen is removed and tension-tested to failure by the apparatus shown at left below. The photo below shows a closeup of the fracture surface of a failed specimen, with the boundaries of the stress corrosion flaws outlined for clarity. The degree of degradation due to the environmental attack is measured by comparing the specimen's post-exposure strength with the original tensile strength of the material. Such characterization is useful in determining structural designs and selecting materials to avoid stress corrosion problems.

In comparison with present industry standards, the breaking load test provides more information with fewer specimens and shorter exposure times; additionally, it is more discriminating of stress corrosion resistances among materials. Alcoa and Langley plan to submit the procedure to ASTM for consideration as a new standard method of test.



A computerized beauty analysis system based on space imaging technology heads a selection of spinoffs for consumer, home and recreational use

High Tech for Milady's Makeup



Shown being demonstrated at the L. S. Ayres department store in Indianapolis, Indiana is a computerized beauty makeover system that incorporates NASA imaging and image analysis technology. Called Elizabeth, it was developed by Elizabeth Arden Research Center.

Just about everyone has seen the dramatic pictures of Mars and Jupiter and Saturn sent back to Earth by NASA spacecraft. They are not pictures in the photographic sense, but images developed from millions of instrument-acquired data bits relayed in digital form to an Earth station. There the data is processed by sophisticated computers that construct and analyze color pictures of the distant planets.

That technology served as the basis for development of an innovative beauty makeup computer introduced last year by Elizabeth Arden, Inc., a subsidiary of Eli Lilly and Company, Indianapolis, Indiana. Appropriately named "Elizabeth," the system was developed by Elizabeth Arden Research Center, an element of Lilly Research Laboratories, also located in Indianapolis. It includes a high resolution video camera, a display screen and a complex computer program that simulates the application of cosmetics on a client's video image, providing the client a personalized beauty makeover. Elizabeth allows freedom to experiment with new looks without the necessity for removing makeup or applying new cosmetics to the client's face.

A makeover session goes something like this:

The client and an Arden makeup artist sit together at a display monitor on which is projected a video image of the client. The computer scans the image to analyze the client's exact skin color, storing this information in its memory as the basis for color recommendations; the computer program is capable of considering thousands of makeup color combinations and their relative color values.

Using a stylus, the artist electronically removes any heavy makeup from the video image. Against a background of the client's actual skin color, the computer displays palettes for all the colors of the various Arden products—foundations, blush, mascara, eye liners, creams, powders and lipsticks. The makeup artist selects and applies the appropriate combinations to create new video images, after discussing with the client her color preferences, lifestyle, desired daytime and nighttime makeup effects, hair and clothing styles.

A four-part split video screen allows comparison of three different makeovers with each other and with the client's original look. The computer remembers how the artist applied colors on the first "new look" video image and, on command, automatically applies new colors selected by the artist on the other images. The computer can zoom in on a small area of the face and display it in magnified view on the monitor, so

At left, a client and an Arden makeup artist view a four quadrant image (closeup below) of the client's face on a video monitor, comparing the client's actual appearance with three alternative "new looks" created by the artist through computer simulation.

that artist and client can examine closely the effects of new color combinations and how they were achieved.

A makeover session takes about 30 minutes and costs $25, which is redeemable with the purchase of Elizabeth Arden cosmetics. For her investment, a client gets three sample looks, instruction in the latest makeup application techniques, and a personalized computer printout for home use.

Dr. John A. Cella, vice president of the Elizabeth Arden Research Center, states that the principal players in the development of Elizabeth were senior mechanical engineer Dr. Thomas A. Cook and the Center's scientists. Looking for ways to analyze the surface of the human skin, they learned of space imaging technologies developed by NASA and others. They contacted the Aerospace Research Applications Center (ARAC), a NASA-sponsored technical information center in Indianapolis, and commissioned ARAC to survey technologies that might be employed in development of a system for measuring the "microtopography"—or profile—along a section of skin. ARAC conducted a comprehensive computer search of technical literature on profilometry and surface roughness measurement and submitted a report detailing developments by Langley Research Center, Marshall Space Flight Center, non-NASA research organizations, and manufacturers of profilometers and associated equipment. Elizabeth Arden Research Center used the ARAC information as a knowledge base for development of Elizabeth, which took two years and an investment of $1 million.

In August 1984, Elizabeth Arden launched a demonstration tour that was to continue into 1985 and cover 45 major U.S. markets (two competing systems were introduced shortly thereafter). The Arden system included three work stations, allowing three simultaneous makeovers. Initial demonstrations were very popular; Elizabeth was booked from morning to night at all three work stations and often there was a sizable waiting list. Comments from cosmetic experts were generally favorable, suggesting that computerized systems might become permanent features of cosmetic makeover and might find further application in such related areas as hair styling and ready-to-wear fashion.

Anti-fog Compound

In the accompanying photo, the model is displaying TRX Anti-Fog Composition, an inexpensive preparation that prevents condensation of moisture on plastic and glass without harming the surfaces of such materials. Manufactured by Tracer Chemical Company, Tampa, Florida, it has a variety of applications—for example, fog prevention for eyeglasses, ski goggles, skin-diving masks, car windows, bathroom mirrors, camera lenses and helmet face shields worn by firefighters or motorcyclists.

The compound was originally developed by Johnson Space Center (JSC) to bar fog formation on astronaut helmet visors and spacecraft windows. The basic composition includes a liquid detergent, deionized water and an oxygen-compatible fire resistant oil.

Started in 1980 as a specialty company providing chemical products for the law enforcement community, Tracer Chemical sought to broaden its product line. Company president Harry L. Humphrey learned of the JSC compound through *Tech Briefs*, a NASA publication intended to advise potential users of NASA technologies available for transfer. Humphrey subsequently obtained a NASA license for manufacture and marketing of the compound and started production in 1981.

Tracer Chemical markets the product under its own label and with the "house brand" labels of other customers. The company has developed a strong customer base in the United States and has found additional markets in the United Kingdom, Japan, Norway and Taiwan. The company reports that its sales of TRX Anti-Fog Composition have provided expansion capital and encouraged the company to look for new opportunities for licensed manufacture of other NASA-developed technologies.

Self-contained Ecosystem

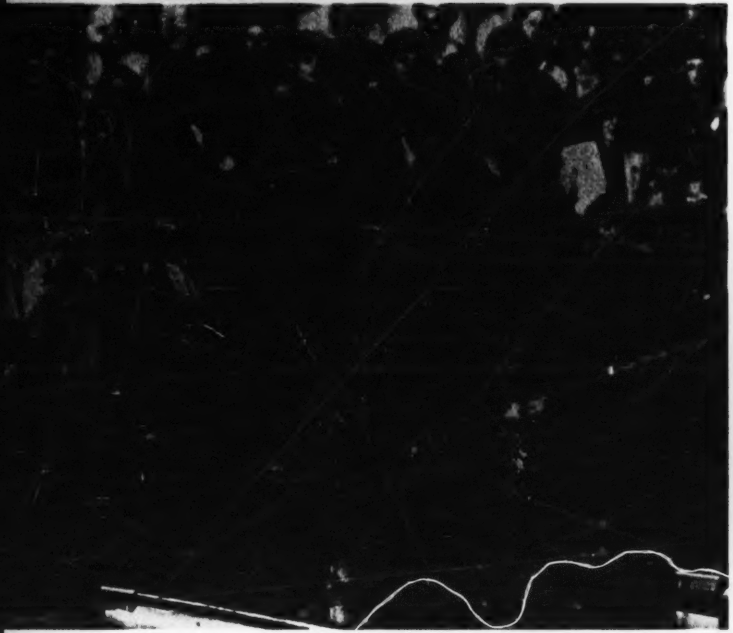
In the course of research on self-contained ecosystems for long-duration manned space flight, a scientist at Jet Propulsion Laboratory developed an ecologically balanced system capable of sustaining plant and animal life for years. That technology is now being employed in manufacture of an ecology display for the home, office or classroom: a five-inch sealed sphere containing six tiny shrimp, several tufts of algae and a clear "soup" of bacteria in filtered sea water—a closed ecosystem in which plant and animal life are mutually sustaining.

Called the EcoSphere®, the system is essentially a care-free aquarium that requires no feeding, no cleaning. Shown in the accompanying photo, it is, in effect, a model of Earth's own ecosystem when provided with an outside energy source: light, which is necessary for algae growth. The light may be indirect sunlight, but for dimly lighted rooms the manufacturer offers an accessory: a fluorescent-lighted life support stand (not shown in the photo) that serves as a base for the sphere.

The algae bask in the light and produce oxygen as they grow. The shrimp—a special species found in Pacific waters—breathe the oxygen while nibbling on the algae and the bacteria. The shrimp and bacteria give off the carbon dioxide needed by the algae for photosynthesis and growth. The bacteria decompose shrimp waste, breaking it down into basic chemical nutrients used by the algae. The algae and bacteria can reproduce; shrimp reproduction has not been verified. The algae can grow indefinitely; no one is sure how long the shrimp may live, but their life spans could conceivably reach 10 years. In test spheres at JPL, shrimp were still thriving after four years.

The EcoSphere is produced by Engineering and Research Associates, Inc. (SEBRA), Tucson, Arizona as a sideline product; SEBRA is normally engaged in research, development and manufacture of medical and scientific instruments and has a long association with the U.S. space program. SEBRA president Loren Acker learned of the JPL technology when he saw one of the sealed flasks on a business visit to a NASA official. Acker obtained a license for the technology, developed a prototype manufacturing process and produced an initial test marketing run of 80 spheres in 1983. The EcoSphere's surprising acceptance led to 1984 production of 200 units, sold through national catalog sales firms. Last October, SEBRA opened a new cleanroom facility in Tucson for sustained production of EcoSpheres; the facility is also conducting research toward development of a broader line of closed ecosystems for all educational levels.

®EcoSphere is a registered trademark of Engineering and Research Associates, Inc.



Bowling Ball Spotting

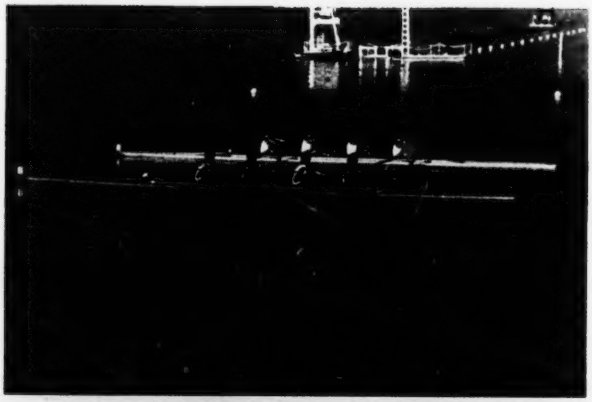
Ebonite International, whose Hopkinsville, Kentucky plant is shown in part at left, has been making bowling balls since 1907 and has become one of the leading manufacturers in the bowling equipment industry with a reputation for innovation. A recent innovation, introduced to the production line in 1984, is what the company calls the most accurate weighing and spotting sytem in operation. Called Exactatron, it was developed by Ebonite engineers with the help of technological information provided by NASA.

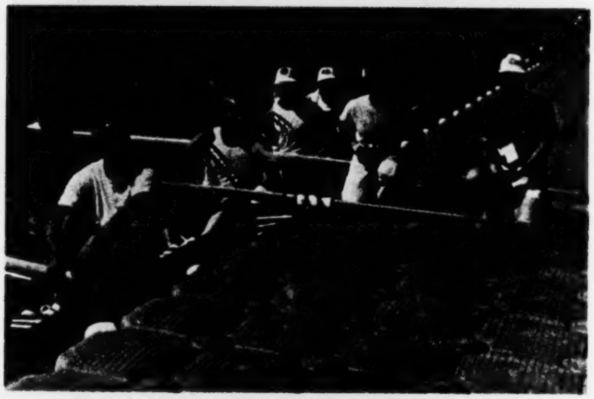
The weighing/spotting system is used to determine precisely the top dead center point of a bowling ball. The ball is "top weighted" during the manufacturing process, meaning that an area near the top is more dense—or heavier—than the rest of the ball. Top weight influences the spinning or hooking action of the ball, thus is important to professional bowlers—such as Earl Anthony (lower left)—who may want to personalize top weight by drilling a hole to modify the weight. This enables them to get a top weight best suited to their individual bowling styles, hence optimum ball performance.

To drill for top weighting, it is necessary to know exactly—within a small fraction of an inch—the top dead center spot. This was formerly accomplished at Ebonite by mechanical measurement, but the company felt it would be possible to develop a more precise system with modern technology. Ebonite outlined the problem to NASA and requested technological information that might be pertinent to development of a more advanced system. NASA conducted a computer search and responded by supplying three technical reports on work performed at Jet Propulsion Laboratory (JPL). One concerned a procedure and a fixture for determining with high accuracy the mass and center of mass of an object, regardless of its shape; the technology was originally developed for the Voyager interplanetary spacecraft but is applicable to many devices that require precise balance. The other reports described JPL research on techniques and apparatus for measuring the viscosities of liquids, which are not always known or easily measured. These reports provided an informational base for Ebonite's development of the Exactratron system for exact spotting of the drilling point for top weighting.

The Exactatron process is described in the accompanying photos. At left center, a ball is mounted on a circular ring then (below) lowered into a cylindrical basin containing a solution of calcium bromide, a liquid that has the proper specific gravity to allow the ball to float. The floating ball rotates momentarily as the heavy portion of the ball settles to the bottom of the calcium bromide bath. When the ball finds equilibrium and stops rotating, a plunger mechanism spots the center point and the marked ball is elevated and removed from the system (right).

Riblet Research





The far rowing shell at left is manned by the men's U.S. four-oar-with-coxswain crew that competed in last year's summer Olympics at Los Angeles, California. The team is shown in closeup in the middle photo, with the coxswain and coach Dietrich Rose (far right) on the dock. This group surprised the sports world by winning the silver medal in an event wherein no U.S. team had won a medal for many years. The silver medalists got an assist from NASA technology originally developed as a means of improving airplane fuel efficiency by reducing the drag caused by the friction of turbulent airflow over an airplane's skin. The technology offers similar advantages for vessels moving through water.

Langley has been working on reduction of skin friction drag since 1976. Most of the airflow over an airplane's surfaces is turbulent, and within the turbulent flow are violent eruptions called "bursts" that are responsible for most skin friction drag and nearly half the total aerodynamic drag on an airplane. Langley's aim is to reduce the intensity of these bursts and to achieve thereby a drag reduction that would translate into lower fuel consumption or higher airplane speed. Researchers at Langley's High-Speed Aerodynamics Division estimate that a turbulent drag reduction of 10 percent would afford fuel cost savings for the U.S. commercial airline fleet on the order of $200–300 million a year.

Experiments at Langley showed that small, barely visible grooves on the surfaces of an airplane can favorably change turbulent airflow and reduce skin friction by as much as 10 percent compared with ungrooved surfaces. The grooves—called "riblets"—are v-shaped with the angle pointing in the direction of the airflow; their depth is about like that of a scratch but they have a pronounced influence on air turbulence. In the Langley experiments, the riblets were machined into flat aluminum samples and tested in wind tunnels; at upper right, Michael J. Walsh, Langley's principal riblet researcher, is adjusting a flat plate preparatory to a wind tunnel run.

An issue of *Tech Briefs*, a NASA publication devoted to technological advances with potential for transfer to commercial use, described the Langley work. The article came to the attention of engineers at 3M Company, St. Paul, Minnesota, who contacted Langley with a suggestion: it would be simpler to mold grooves into a lightweight plastic film with adhesive backing and press it into place on an airplane. This technique would have an additional advantage in that riblet film could be applied to existing aircraft as a relatively economical retrofit measure. The company offered to design and produce test riblets in tape form.

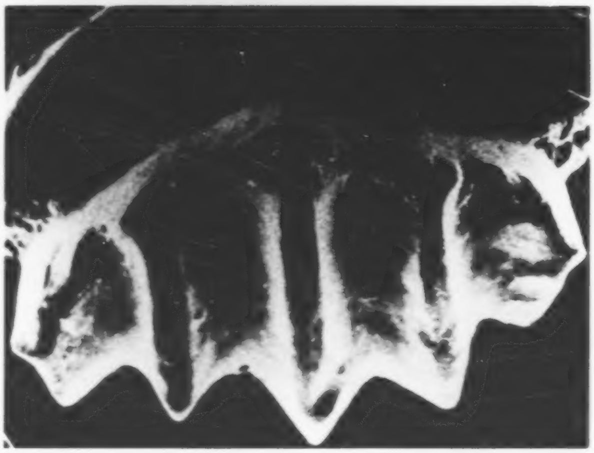
Applying its expertise in producing decorative films for commercial uses, 3M's Decorative Products

Division developed experimental adhesive-coated plastic films with precisely machined riblet surfaces in a variety of designs. Tested at Langley, they were found to reduce turbulent drag as effectively or better than machined aluminum surfaces with the same groove shapes and depths.

Encouraged by the test results, 3M reported the development to The Boeing Company, Seattle, Washington, the world's largest producer of commercial transport aircraft. It interested Boeing engineers, among them Doug McLean, a member of the Flight Research Institute (FRI) in Seattle, a non-profit organization, supported by Boeing and the University of Washington, that provides members opportunities to participate in research projects of an avocational nature. With support from FRI, McLean and a small group of engineers undertook the project of testing the riblets on an Olympic rowing shell. At McLean's request, 3M agreed to provide riblet film for several shells. In a series of tests with a one-person racing shell, the FRI group measured a total drag reduction of about six percent—about what was expected, based on Langley tests. Armed with a number of grooved film sheets and data from their rowing tests, McLean and another FRI member journeyed to the Los Angeles Olympic compound, where they persuaded coach Dietrich Rose to try the riblets in the four-oar-with-coxswain competition. At bottom left, the film is being applied to a shell.

Earlier, when riblet research was already well advanced, Langley had found confirmation of grooving's efficacy in a clue from nature: it was learned that fast-swimming sharks have riblet-like projections on their skins. Called dermal denticles, they are made of the same material as sharks' teeth and typically have four or five tiny grooves on what appears to the naked eye to be a smooth surface. Nature's version of the riblet is shown in the closeup of a dermal denticle (right) magnified 3,000 times.

The Olympic silver medal story is, of course, only an interesting sidebar experiment in a Langley/3M research program of broad potential for the future of air transportation. Considerable research remains and Langley is preparing for the next step: flight test of a Gates Learjet business transport whose forward fuselage is being fitted with 3M riblet panels measuring approximately two feet by 13 feet. Interest is evident at Boeing and at Lockheed-Georgia Company, Marietta, Georgia, a major producer of military aircraft; both companies have initiated their own riblet research programs. Langley has set a long range goal of doubling the demonstrated 10 percent turbulent drag reduction, which would provide a dramatic five percent fuel saving for airlines.



Adaptation of space remote sensing technology to diagnostic imaging highlights spinoffs in the field of health and medicine

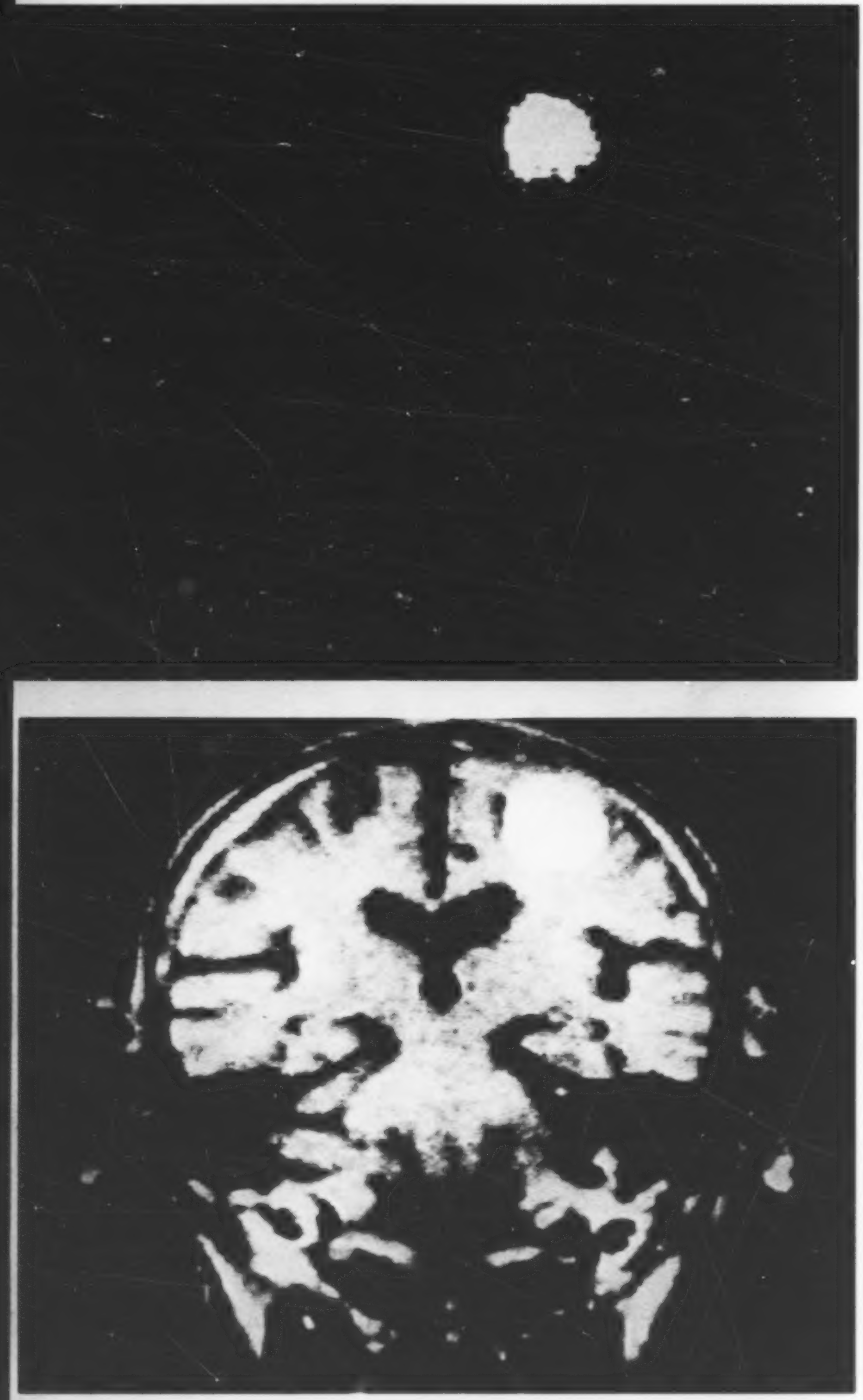
New Window Into the Human Body

Nuclear magnetic resonance (NMR) is a relatively new technique for viewing the inner parts of the human body. Instead of possibly dangerous x-rays, it employs a magnetic field and radio waves to create body images from which radiologists can extract diagnostic information. It offers certain advantages over other body-scanning systems, for example, it is noninvasive and it can penetrate bone, which normally blocks x-rays. NMR also has its limitations because it has not yet been fully developed; although NMR equipment is being produced commercially and the images used clinically, NMR is still largely an experimental technique being studied and advanced by a number of medical institutions.

NMR images provide a vast amount of anatomical and physiological information, which is at once an advantage and a disadvantage. The disadvantage is that the NMR scanner collects a great amount of redundant data, inducing a degree of complexity that makes interpretation difficult. In some instances, where a patient has a complicated problem, a radiologist may have to analyze 50 or more NMR images to make a proper diagnosis.

Seeking a way to overcome this difficulty, Michael Vannier, M.D., hit upon the idea of employing satellite image enhancement technology. Dr. Vannier is now assistant professor of radiology at Mallinckrodt Institute of Radiology, Washington University Medical Center, St. Louis, Missouri, but in earlier life he was a NASA engineer. Thus, he was able to recognize the similarities between NMR imaging and the space technique of Earth resources imaging. The NASA-developed Landsat satellite takes electronic pictures in several segments of the light spectrum. Its detectors recognize unique "signatures" of various Earth features—crops, water, buildings or forests—and send the information to ground stations in a voluminous flow of digital data. By itself, the raw data would be extremely difficult to interpret, but use of NASA's computerized image processing technology makes possible easier analysis. A computer program analyzes the data, sharpens contrasts, eliminates confusing detail and produces Earth images in which the various features appear in different colors.

Dr. Vannier contacted NASA to see if Landsat processing techniques could be applied to medical imagery. He enlisted the help of Bob Butterfield, manager of technology integration at Kennedy Space Center, and Douglas Jordan, engineering manager of the Remote



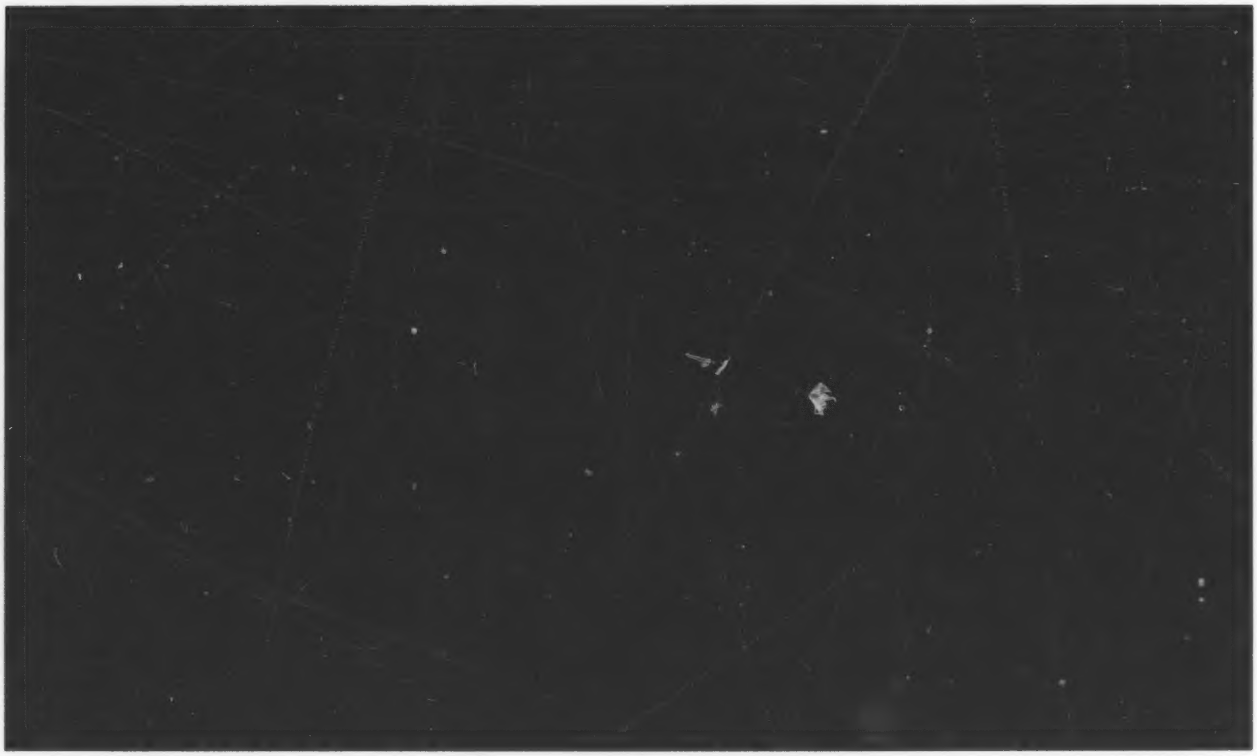
Nuclear magnetic resonance (NMR) is a promising new technique for diagnostic body scanning, but NMR imagery is difficult to interpret. Space image enhancement technology offers a means of improving black and white NMR images and facilitating earlier diagnoses. The upper image is a computer processed color composite of an NMR head scan, showing a brain tumor (white area near top). In the lower image the enhancement process is taken a step further to create a "theme map" in which each color corresponds to a different type of tissue, with the tumor sharply defined.

Sensing and Image Processing Laboratory at the University of Florida in Gainesville. Dr. Vannier and Butterfield took a number of NMR scans to the Florida laboratory, which has a highly sophisticated computer used in analysis and classification of Landsat data. The computer program processed the NMR scans just as it would Landsat information, combining multiple black and white NMR images into a single, realistically-colored composite picture. "These pictures look real," says Dr. Vannier, "just as if you lifted a slice right out of the human body."

The trio of Vannier, Butterfield and Jordan, with help from other representatives of their three organizations, took their research one step further and learned how to make "theme maps" of the human body. In Earth resources observation, Landsat signature data can be processed to create a thematic image, for example, one that separates wheat fields from all other crop areas. In medical use, the computer program searches the NMR image for a signature of interest to the radiologist—a hematoma, or blood clot in the brain, perhaps—and colors any area that has that particular signature. In the hematoma example, the resulting theme map shows the precise demarcation between the blood clot and the parts of the body still unaffected, where original NMR scans define such borders poorly. Such tissue maps should facilitate earlier diagnosis in many disorders.

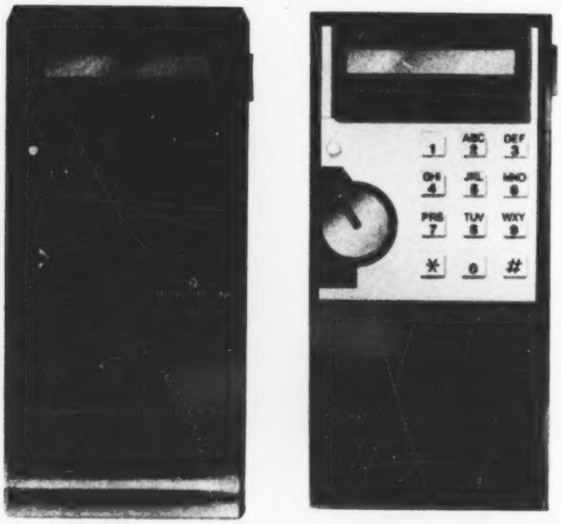
Dr. Vannier has collaborated with other physicians in applying satellite technology to NMR scanning in scores of patient studies. He is now engaged in advancing the process one more step: converting the Landsat computer program to a form compatible with the type of computer integral to the NMR system; that would allow expansion of the new imaging technique to all NMR centers.

The Mallinckrodt Institute radiologist feels that satellite image processing will become a regular part of NMR body scanning, although it may be in a much different form than in the initial applications. "Even these first crude experiments show that the potential is very great," he says. "Satellite imaging has opened a new window into the human body."



A space-developed computer program created the color composite at left from three black and white NMR images. It is a chest scan showing a tumor mass at top center. In the theme map at right, the borders of the tumor mass (top center) are precisely outlined.

Heart Monitor



The device pictured is MONITOR ONE, a portable, computerized cardiac system that offers physicians a new approach for monitoring ambulatory patients with coronary artery disease. The cardiac monitor, alerts the patient to impending high-risk cardiac events by continuously evaluating the electrocardiographic signals generated by the heart. MONITOR ONE, which incorporates NASA technology, is the product of three years of research and development by Q-Med Inc., Clark, New Jersey.

The upper photo shows MONITOR ONE with its cover in place and with the cover removed. The latter picture shows the telephone-like keyboard for programming the microprocessor-controlled system and the circular lithium battery for the memory storage section. The main battery pack, consisting of four small nickel cadmium rechargeable batteries, is below the keyboard. The cardiac display window is at the top of the unit and adjacent to it is a connector for the three long-life high silver content electrodes (lower photo). Approximately six inches long and three inches wide, MONITOR ONE weighs 14 ounces; it may be attached to a patient's garment or carried in a pocket, and it does not interfere with daily routine.

MONITOR ONE may be worn for days, weeks, months or years. It evaluates every heartbeat and makes immediate decisions as to the normalcy or abnormalcy of the beats. Each abnormal event defined by the computer is stored for later review by the physician, who may program various thresholds for different patients. MONITOR ONE not only enables a physician to track a patient's progress over a long period, but also allows him to evaluate the efficacy of drug treatment and to adjust dosages accordingly.

MONITOR ONE was developed by three co-founders of Q-Med Inc.: Michael W. Cox, president; Dr. Richard I. Levin, vice president/medical director; and Robert A. Burns, director. They recognized early in the R&D program that the key to successful development of an ambulatory mode system was the electrode—it had to last for long periods, provide high fidelity and not require constant skin abrasion in order to function properly. NASA's Johnson Space Center (JSC) had successfully developed advanced electrodes for monitoring the heart action of Space Shuttle astronauts. The Q-Med team learned of the JSC technology and tested samples of the NASA electrodes; they proved to be ideal for MONITOR ONE. Q-Med was granted an exclusive license to manufacture and market the electrodes and in August 1984 the company was advised by the Food and Drug Administration that it could begin marketing the MONITOR ONE system. Initial deliveries of MONITOR ONE, manufactured for Q-Med by Rodale Electronics, Garden City, New York, were made last January.

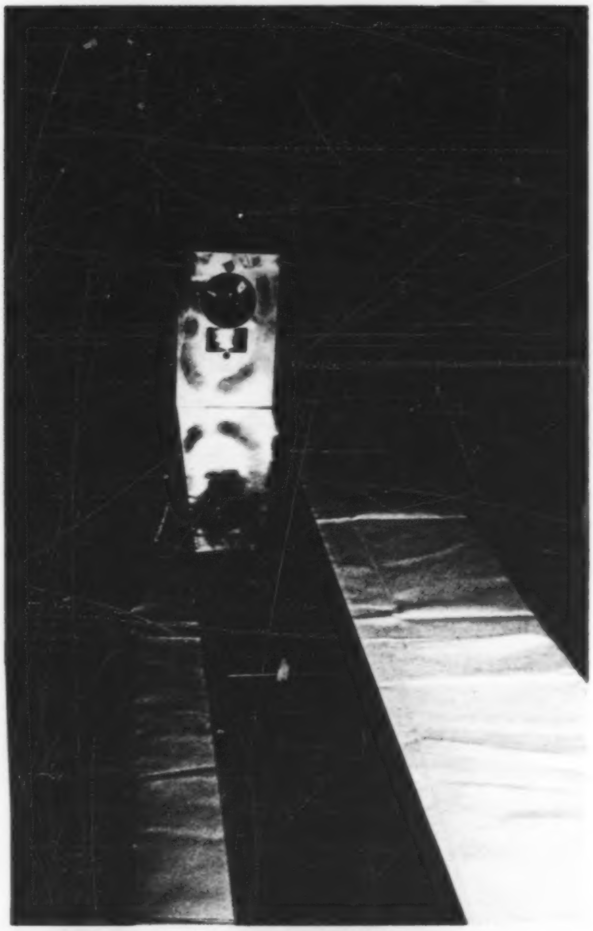
Ocular Screening System

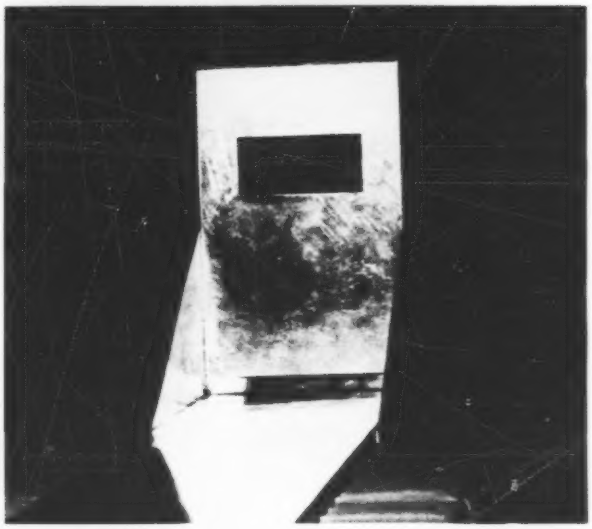
A NASA-sponsored application engineering project, designed to meet a need for a low-cost method of vision examination, has resulted in successful development of an ocular screening system based on aerospace technology and formation of a company—Medical Sciences Corporation (MSC), Wedowee, Alabama—to provide screening services. The system was jointly developed by Marshall Space Flight Center and Dr. Joe Kerr, now president of MSC. Several Alabama ophthalmologists served as medical consultants on the project.

Evaluated in field tests of more than 5,000 subjects prior to pre-market authorization by the Food and Drug Administration, the screening system photographically records the reflective properties of the inner and outer parts of both eyes simultaneously. From this information, it is possible to determine whether a person has normal eyes, is near-sighted or far-sighted, has cataracts or any other problems related to the optical properties of the eyes. Capable of testing an individual in three minutes, the system is designed for safe, convenient screening of large groups. Its major advantage is greater sensitivity than the traditionally-used eye chart. For example, in a test of 1,657 Alabama children, only 111 failed the chart test but the MSC system found 507 abnormal conditions; these abnormalities were verified by ophthalmological follow-up.

The system's key element is a photorefractor that consists of a 35-millimeter camera, a telephoto lens and an electronic flash. At upper right, Dr. Joe Kerr is pointing the photorefractor toward a subject peering through a head positioning hood located 13 feet from the camera (lower photo). The flash sends light into the subject's eyes and the light is reflected from the subject's retina back to the camera lens. The photorefractor analyzes the retinal reflex generated by the flash and produces an image of the subject's eyes in which the pupils are variously colored; the nature of a defect, where such exists, is identifiable by a trained observer's visual examination of the pupils.

The ocular screening system is portable, rugged, requires no maintenance and provides consistently interpretable results. MSC has designed motorized vans, housing a screening system and a small computer, for conducting tests at schools, industrial plants, military bases or civic organizations. The film and the computer disc—which contains subject data and image identification—are shipped to MSC's Wedowee headquarters for analysis and coordination. Results of a test are sent to the subject in five days.



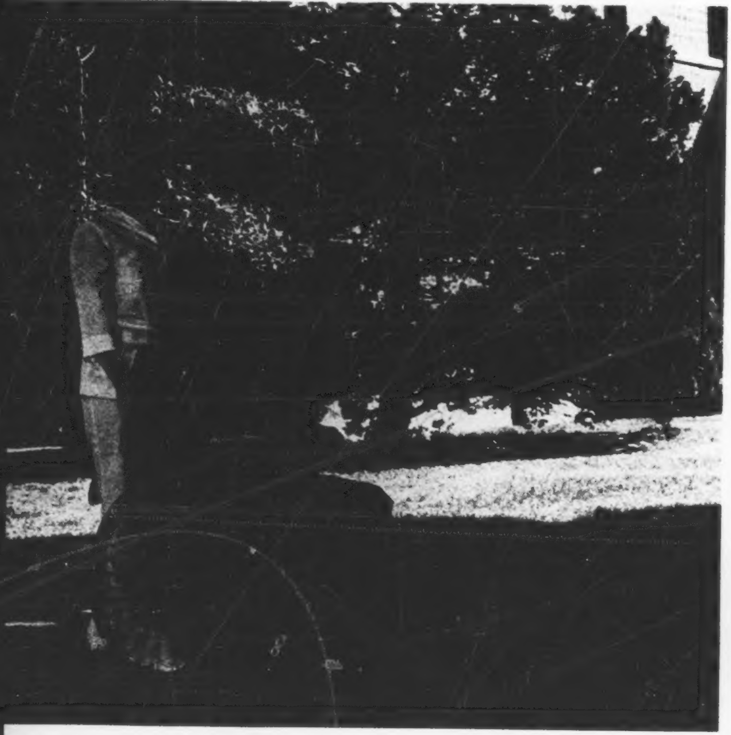


Advanced Wheelchair

More than one million people in the United States rely on wheelchairs for mobility and many of them have difficulties with existing types of chairs. Among the problems are heaviness, which makes the chair hard to handle, frequent breakdowns and limited chair lifetime, which results in high life-cycle costs. Recognizing these problems, the Veterans Administration and the National Insitute of Handicapped Research have sponsored several wheelchair research projects.

Most projects have focused on improving components rather than on development of an entirely new chair. One cooperative effort, however, undertook full-scale development—from analysis of requirements through prototype fabrication and evaluation—of an advanced wheelchair based on aerospace technology. Langley Research Center teamed with the University of Virginia (UVA) Rehabilitation Engineering Center, Charlottesville, Virginia in developing the prototype shown at left. NASA funded Langley's part of the program; UVA funding was provided by the National Institute of Handicapped Research. Also participating in the program is the NASA-sponsored Research Triangle Institute (RTI) Application Team, Research Triangle Park, North Carolina.

The Langley/UVA developers employed aerospace computerized structural analysis techniques to arrive at the optimum design and used aerospace composite materials, which are generally lighter but stronger than metals. The resulting chair weighs only 25 pounds but has the same strength and weight-bearing capability as a 50-pound stainless steel wheelchair. It can be collapsed for auto stowage as shown below; it also features a solid seat, wheel guards, dynamic brakes and shaped hand rims, a footrest with smooth contours to aid in opening doors. Langley built four test models of the chair; the prototype was well received when shown last year at the International Conference on Rehabilitation Engineering in Ottawa, Canada. The RTI Application team is discussing possible commercial production of the advanced wheelchair with several interested manufacturers.



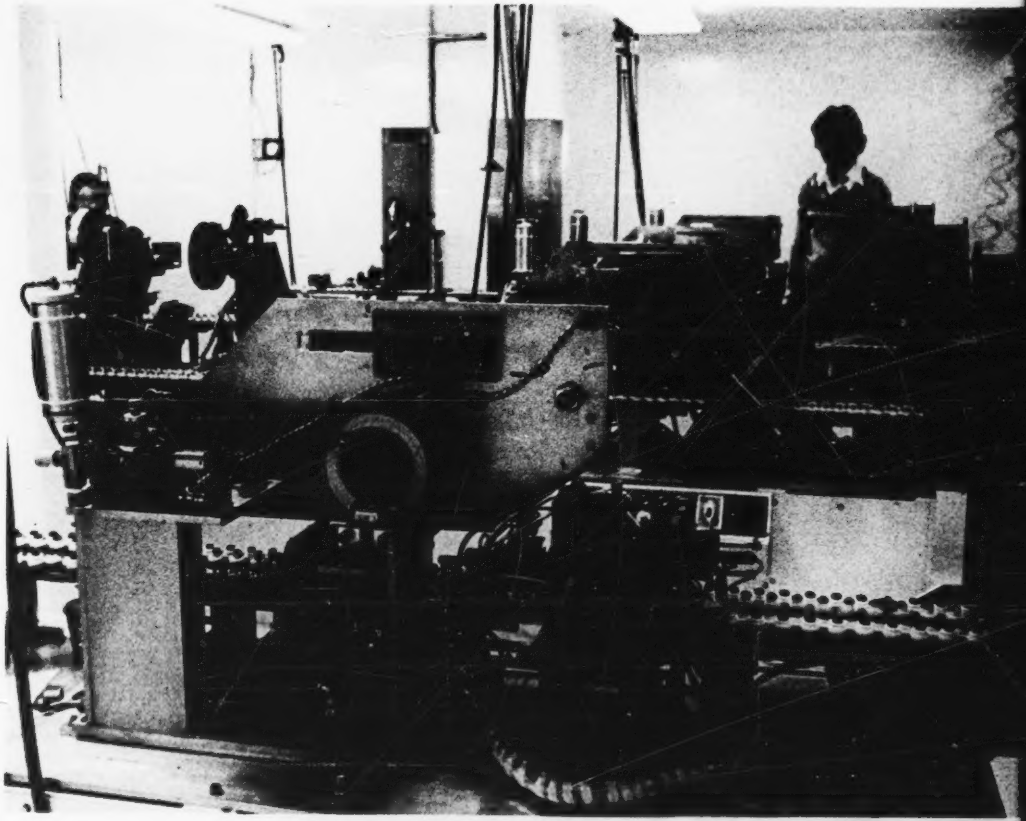
Vehicle Controller

For the Apollo lunar landings of the early 1970s, NASA developed a Lunar Rover to permit exploration of the moon miles from the immediate vicinity of the landing site. The Rover was designed to allow an astronaut to drive one-handed, using an airplane-like joystick to accelerate, brake and steer the vehicle. That technology is being applied to a system that offers severely handicapped people an opportunity to drive highway vehicles, providing them mobility for more productive lives.

Called UNISTIK, the system is being developed by Johnson Engineering Corporation, Boulder, Colorado under the joint sponsorship of NASA and the Veterans Administration Rehabilitation Engineering Research and Development Service, Washington, D.C. The UNISTIK vehicle control system employs a joystick that combines the functions of steering wheel, brake pedal and throttle pedal, thus can be operated by handicapped persons who have no lower limb control and only limited use of upper extremities. The driver simply moves the joystick forward to accelerate, backward to brake and from side to side for steering; any combination of these movements can be used. The UNISTIK control is shown in the upper photo; it is undergoing extensive testing in a Ford van, pictured at right during a demonstration in Washington, D.C.

The UNISTIK system is designed as an addition to an ordinary van. The patented modification utilizes digital electronics, microprocessors and high-torque actuators—one each for brake, throttle and steering—all easily installed entirely under the dashboard as a "bolt-on" accessory. The installation allows full use of the vehicle's normal controls by able-bodied persons; a push of a button switches from regular to UNISTIK control or vice versa. Under way since 1981, the project is now in its final development phase, expected to culminate in production of the system beginning in March 1986.

SPACE TECHNOLOGY FOR THE HANDICAPPED
Johnson Engineering Corporation

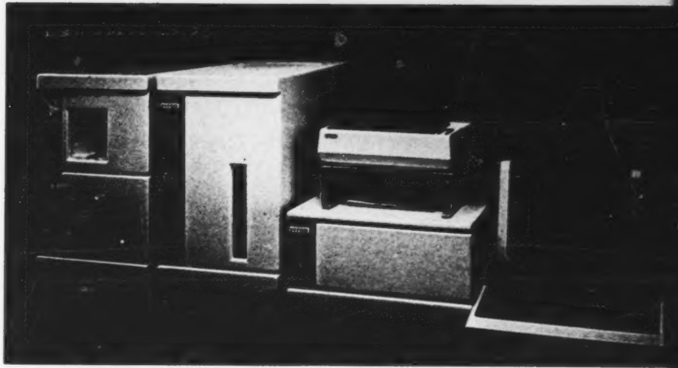


Microbe Detector

The above photo shows a part of the Hazelwood, Missouri plant of Vitek Systems, Inc., a subsidiary of McDonnell Douglas Corporation, where Vitek is producing a device known as the AutoMicrobic System® (AMS). Both the product and the company owe their existence to technology developed in NASA's Voyager interplanetary exploration program.

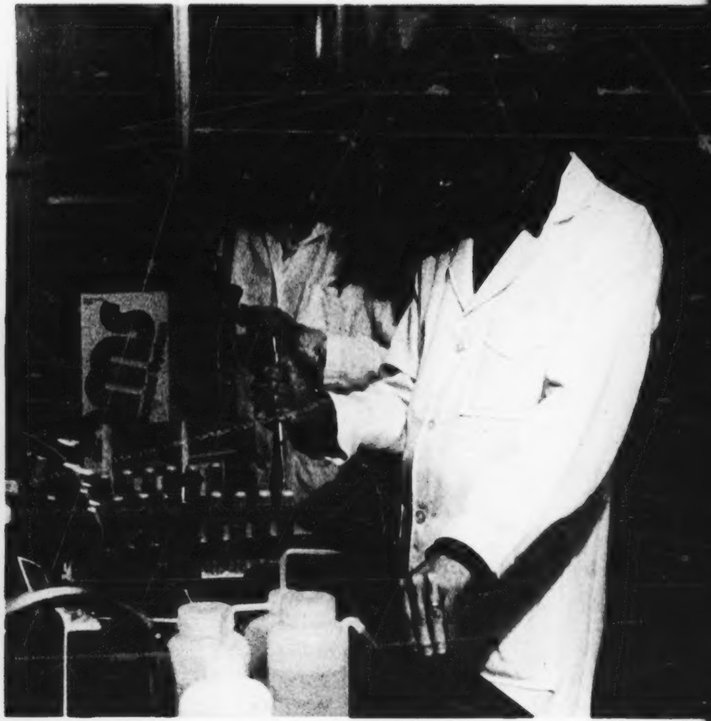
For Voyager, McDonnell Douglas developed a Microbial Load Monitor (MLM) to detect bacterial contamination aboard the spacecraft. Under another NASA contract, McDonnell Douglas studied an expanded MLM with the additional capabilities of detecting and identifying bacterial infections among the crew of a manned mission to Mars. The Mars flight is still in the future, but McDonnell Douglas, recognizing the MLM's commercial potential, invested further effort in converting the Voyager/Mars mission technology into a time-saving system for analyzing a patient's body fluid samples.

McDonnell Douglas created the Vitek subsidiary to manufacture and market the AMS and introduced the system to hospital use in 1979. Since then Vitek has delivered several hundred units, mostly to medical laboratories, but the system is also finding acceptance in industrial laboratories of companies producing pharmaceuticals and food products. At right is the latest version of the system, the third generation AMS III, which performs the identification and analysis functions much faster than the original system.



AMS offers a means of reducing hospital stay times by allowing quicker identification and earlier treatment of an infection. The traditional method of testing for disease-producing microorganisms, or pathogens, involves three steps. First, specimens of body fluid—urine or sputum, for example—are prepared in cultures. Next, the cultures are incubated for two to four days. Then microbiologists study the cell growth that took place during incubation, from which they can determine the presence of pathogens and identify them.

AMS does the same job quicker. Instead of the petri dish customarily used to prepare cultures, AMS employs test kits (right center)—disposable, plastic cards approximately the size of a playing card, each card containing from 16 to 30 wells and each well holding a different chemical substance. There are two

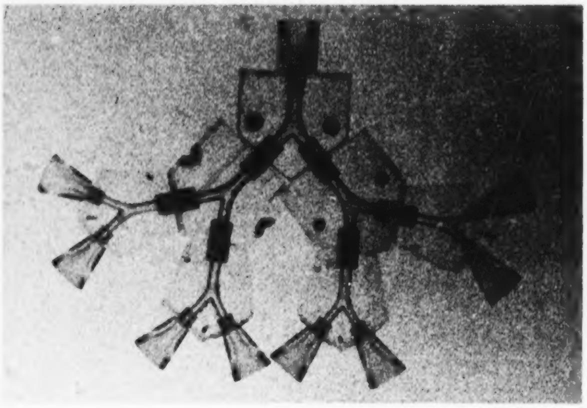


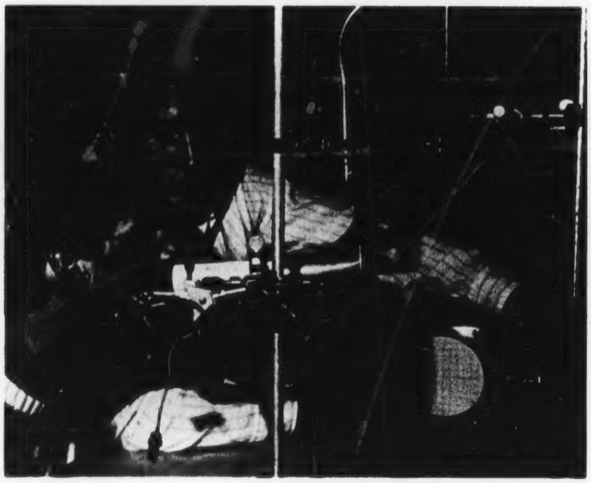
types of cards: Identification Cards and Susceptibility Cards. A body fluid sample is injected into the Identification Card (above right) and organisms in the sample react with the chemicals in the wells. Mounted in trays, the cards are placed in an incubator/reader module of the AMS. Scanning each well once an hour, the system "reads" the reactions taking place, compares them with information in the computer and thus identifies the organism—or gives a negative report when no organism is present. Identification data for each specimen is reported on a display screen and also provided in printout form.

Once an organism is identified, the body sample goes into another plastic card—called the Susceptibility Card—whose wells contain a number of different antibiotics. This card is similarly inserted into the system for computer examination, which results in a report as to which antibiotic is most effective against the organism; there may be more than one, in which case a physician would make the final selection. The whole process, including identification and susceptibility determination, takes from four to 13 hours, compared with two to four days for culture preparations. AMS can handle as many as 240 specimens at one time.

AMS enables the microbiology laboratory to furnish guidelines for antimicrobial treatment within one day of specimen collection, a large-scale time saving over standard laboratory methods. In addition to its promise for reducing hospital patient stay time, AMS offers important advantages to the laboratory: it minimizes human error, reduces technician time and increases lab output. Aside from medical use, AMS is also a useful tool for industrial laboratories in such applications as detection and identification of organisms during incoming, in-process and finished goods inspections; identification of biological indicators in sterilization processes; and in-plant environmental testing.

®AutoMicrobic System and AMS are registered trademarks of McDonnell Douglas Corporation.



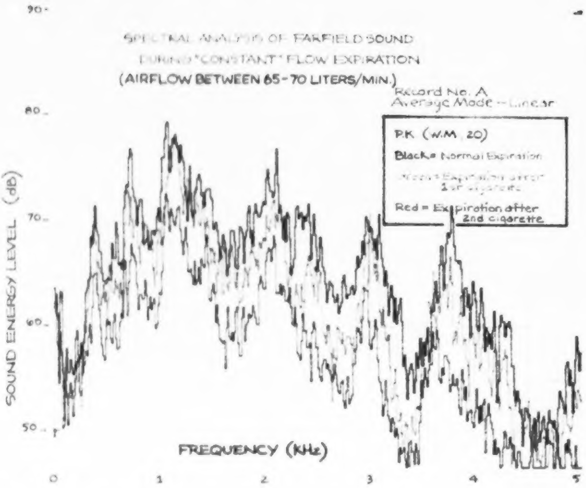


Lung Diagnosis

Disabling lung illnesses may develop from exposure to adverse occupational or environmental conditions, innate defects in the anatomy or function of the lungs, allergic responses, asthma, prolonged cigarette smoking and other conditions. Early detection, accurate diagnosis and immediate initiation of therapy improve the chances for successful treatment to forestall later stages of pulmonary illnesses. There is evident need for new, more sensitive, and more specific methods of insuring early detection of pulmonary abnormalities.

NASA research in aeroacoustics, the study of aircraft sound production toward reducing noise and vibration, has provided a theoretical basis for a mathematical-physical model of the production of human respiratory sounds, specifically "breath sounds." In theory, a particular pulmonary illness causes characteristic anatomic changes or changes in the reactivity of the bronchi, and therefore of airflow through different regions of the lung. Since early changes in respiratory response to a variety of stimuli are indicators of later disease, it is imperative to develop highly sensitive methods of detecting and following the time course of such early changes.

A theory of breath sound generation based on the interactions of vortices in the pulmonary airways has been developed and validated through extensive test data acquired by Langley Research Center/Medical College of Virginia (Richmond) researchers, using instrumented lung models they have developed (upper left). The intent of the project is to develop a technique of sufficient sensitivity to break down human respiratory sounds—as these sounds are changed by dysfunction—into their spectral frequency and amplitude components. In human testing (upper right), changes in breath sounds in the pulmonary airways are recorded and analyzed by a number of complex instruments normally associated with aeroacoustic research. The graph shows the marked changes that occur in the sound spectrum of a young healthy subject after inhaling cigarette smoke; the black line shows normal expiration, green represents expiration after one cigarette and red indicates expiration after a second cigarette.



The research team includes Langley aeroacoustics experts Dr. Jay C. Hardin and Dr. John M. Seiner; Dr. John L. Patterson, Jr., principal investigator, Joseph E. Levasseur, together with medical and pre-medical students and collaborating faculty of the Medical College of Virginia; and the NASA-sponsored Research Triangle Institute Applications Team, Research Triangle Park, North Carolina. Bruel and Kjaer Instruments, Inc., Marlboro, Massachusetts, is supporting the project with engineering consultation and equipment. Interested in the system's commercial potential, Bruel and Kjaer predicts a market for a diagnostic and monitoring device in industrial employee check-up centers, as well as in the offices of specialists in respiratory disease, in clinics and in hospitals.

Bone Analyzer

One of the dangers of long-duration space flight is disuse osteoporosis, a form of bone deterioration induced by astronaut inactivity under weightless conditions. However, the crew of the Skylab 4 interim space station demonstrated, on an 84-day mission in 1973, that adequate food and exercise can reduce bone loss. Contemplating future manned missions that might run two years or more, NASA sought a practical, inexpensive, noninvasive way of making quantitative measurements of bone stiffness and mass, a system sensitive enough to monitor and evaluate small changes. This would enable comprehensive studies of the effects of nutrition and exercise, toward developing food/exercise programs to prevent astronaut bone loss. Since bone deterioration affects a substantial portion of the U.S. population, it would also meet a need—in hospitals, clinics and convalescence homes—as a tool for diagnosis of bone abnormalities caused by disease, aging and disuse, and a means of evaluating fracture healing.

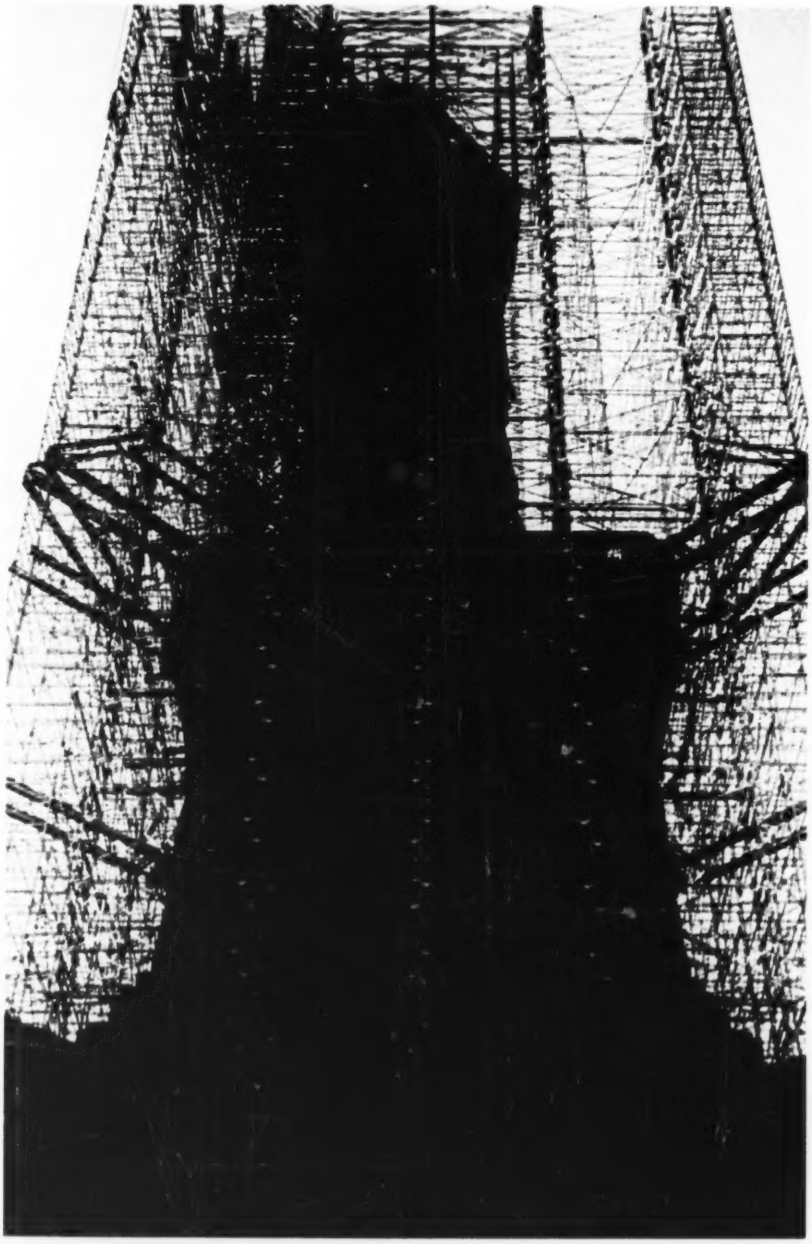
Such a system is now in final development status after a decade of effort by the Biomedical Research Division of Ames Research Center, which funded and teamed with Dr. Charles R. Steele, Professor of Applied Mechanics at Stanford University's Department of Aeronautics and Astronautics. In 1977, the Ames/Stanford team developed a prototype microprocessor-controlled bone probe system; built by Oxbridge Associates, Sunnyvale, California, it was known as SOBSA (Steele-Oxbridge Bone Stiffness Analyzer). Tests with human subjects indicated that SOBSA could be used clinically but it had certain limitations with respect to accuracy, sensitivity and operator training requirements. Through its Technology Utilization Program, NASA funded construction of an advanced SOBSA-2 featuring improvements in those areas.

SOBSA-2 is a computer-controlled impedance probe system in which bone stiffness is determined quantitatively by measuring responses to an electromagnetic shaker. The subject's bone is constrained at each end (above), the shaker applies vibration and the probe measures the resulting impedance (electrical resistance), providing a basis for computer analysis and determination of bone stiffness; the data acquisition and analysis module is shown at left. Such information can be used by physicians to detect the presence of bone disease, to measure the extent of deterioration, and to aid in prescribing therapy.

SOBSA-2 has been further refined and it is now undergoing clinical testing at Stanford University Orthopedic Clinic, performing measurements on patients before and after total hip, knee, shoulder and elbow replacements. The latest model has a more powerful controller, permitting extensive data collection and analysis in a short time. By the end of 1985, it is expected that the system will have demonstrated the desired accuracy and repeatability over a wide range of subjects.

Among spinoffs for structural security and public safety is a corrosion resistant coating for America's symbol of freedom

New Life for Miss Liberty



On October 28, 1886, President Grover Cleveland led a million Americans in the dedication of the Statue of Liberty, a gift from the people of France intended to symbolize American freedom. Next Fourth of July, to commemorate Miss Liberty's 100th anniversary, the statue will be rededicated after extensive renovation and refurbishment. Among many rejuvenating measures designed to repair the ravages of a century and insure Miss Liberty's long-term survival is a protective coating that originated in NASA research on corrosion resistant materials.

Liberty's designer, French sculptor Frédéric Auguste Bertholdi, once boasted that his creation would last as long as the pyramids of the Nile. But Bertholdi reckoned without the degradation caused by the cumulative effect of construction flaws, accidents, two million visitors a year and the corroding impact of salt spray, fog and atmospheric pollution. In 1980, a close inspection by the National Park Service, Liberty's custodian, revealed signs of corrosion and other deterioration of the structure. Though not immediately threatening, the damage was sufficient to warrant action. A French-American Committee for Restoration of the Statue of Liberty was formed to draw up an architectural-engineering rehabilitation plan. Spearheaded by Chrysler chairman Lee Iacocca, an effort to raise restoration funding from private sources was organized and the Liberty life-extension program was set in motion.

The monument is being

rehabilitated from pedestal to torch. The century-old structural steel skeleton is being reinforced where needed with modern stainless steel alloys. The statue's copper skin is getting a thorough cleaning and seams in the skin are being closed with a sealant for improved weather resistance. Tests of the skin showed it had weathered well so, in order to preserve the historic blue-green patina, the planners rejected application of exterior protective films. However, corrosion protection is being provided for the interior structure by a primer coating known as IC 531, an aerospace spinoff product manufactured by Inorganic Coatings, Inc., Malvern, Pennsylvania. The coating was developed by Goddard Space Flight Center as a means of protecting gantries and other structures at NASA's primary launch site, Kennedy Space Center (KSC).

KSC is located on Florida's Atlantic Coast, thus its launch facilities require greater corrosion protection than is needed inland because of constant exposure to salt spray and fog. Seeking to reduce maintenance costs at KSC, Goddard conducted a research program aimed at development of a superior coating that would not only resist salt corrosion but also protect KSC launch structures from the very hot rocket exhaust and the thermal shock created by rapid temperature changes during a space launch. The successful research effort produced a new type of inorganic coating.

Goddard's research in the early 1970s was based on chemistry first investigatged in the 1940s. Although the early chemistry proved very effective against corrosion, it was not practical to apply or cure in a production situation. NASA's development of a high-ratio 5.3:1 potassium silicate solved all of the practical application problems while improving on the original silicate/zinc chemistry. The new high-ratio formula provided economical, long-term protection with a single application in a marine environment.

In 1981, NASA granted a license for the coating to Shane Associates, Inc., Wynnewood, Pennsylvania. The following year, Inorganic Coatings signed an agreement to become sole manufacturer and sales agent under the Shane license. The latter company assigned the trade name IC 531 to the NASA compound.

Because IC 531 is water-based, it is non-toxic, non-flammable and has no organic emissions. The high ratio silicate formulation bonds to steel and in just 30 minutes creates a very hard ceramic finish with superior adhesion and abrasion resistance. It mixes and applies easily with standard equipment and thus offers advantage in fewer labor hours per application.

Of particular importance is the compound's long lifetime. Although commercial applications by Inorganic Coatings are relatively recent, hence provide no long-term results, the coating has shown outstanding corrosion resistance in a number of test applications over the past decade. It has been tested in severe environments around the world, for example, in laboratory salt spray chambers; on test panels at Kennedy Space Center; on bridges, such as California's Golden Gate and Oregon's Astoria River Bridge; and on antenna installations in California, Hawaii and Canton Island in the South Pacific. Inspections made five to nine years after application showed coated structures virtually free of corrosion, and thickness measurements disclosed almost no film loss despite long exposure to sun, moisture and salt.

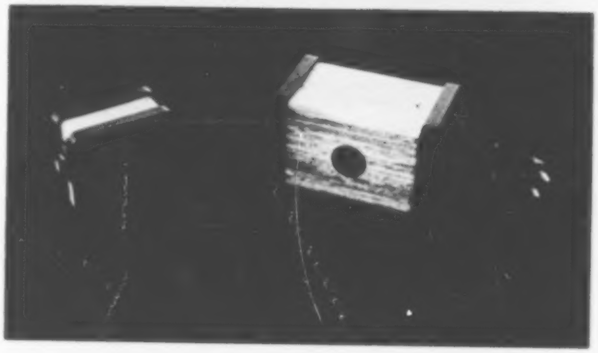
Obscured by scaffolding, the Statue of Liberty (far left) is undergoing extensive renovation and refurbishment after discovery of deterioration caused by corrosion and other factors. Among life-prolonging measures is a long-life corrosion resistant coating being applied to the interior structure. Known as IC 531 and manufactured by Inorganic Coatings, Inc., it is easily mixed on site (lower left), easily applied (below) and has superior adhesion and anti-abrasion characteristics.

Visual Alert System

At right, inventor James Campman of Grace Industries, Inc., Transfer, Pennsylvania, is displaying a door installation of the company's Concept I Visual Alerting System (VAS), a multipurpose security device for home or office that combines visual and audible alerts. Intended primarily as a burglar alarm, smoke alarm, door or telephone alert for hearing-impaired people, the VAS is a second-generation spinoff based on electronic circuitry originally developed under contract to Langley Research Center.

The VAS consists of two basic components shown in the lower photo: an audio transponder (white unit) and a companion receiver. Attached to a door, window or telephone, the transponder detects vibrations caused by such noises as a knock on a door, a break-in attempt, opening of a window or a ringing telephone. The vibrations are converted into a loud beeping tone that is transmitted to the receiver plugged into an electrical outlet. The receiver, in turn, switches on a lamp or causes it to flash. The receiver's sensitive electronic circuitry also detects sounds made by smoke alarms and provides a visual alert. The VAS is designed to deter intruders by the loud beeping noise and additionally to serve as an economical, reliable visual signaling device for those unable to hear sonic alerts.

The VAS traces its technological lineage to low noise, low voltage circuitry developed by Applied Cybernetics Systems Inc. for NASA/Langley as part of a telemetry system for relaying spacecraft data to ground station computers. James Campman, then Applied Cybernetics president, later left the company and formed Grace Industries to manufacture and market security devices based on the Langley technology. Grace Industries' first development, which employs the circuitry developed for satellite data relay, was a sensitive gas detector capable of sensing hydrocarbon gas concentrations of less than 50 parts in a million. Called the Electronic Nose®, it is primarily an arson detection device that senses post-fire accelerants—such as gasoline, benzine and other combustibles—used by arsonists to speed up fire spread. The unit saves investigators time and expense by allowing rapid acquisition of physical evidence for use in courts; it has also proved to be an arson deterrent because its fast, reliable analyses enable accelerated efforts to identify and prosecute arsonists.



It is widely used by police and fire departments and by insurance companies; it is also in use at several colleges and universities that offer criminal justice courses. In a related application, the Electronic Nose is in service with a number of oil companies as a means of detecting gas leaks in refineries and on oil rigs.

Grace Industries has experienced a steady 10 percent annual growth and is now producing the Electronic Nose at the rate of about 1,000 units a year. The success of that device provided capital to expand the company's product line with the Visual Alerting System, which was introduced in 1984. Grace Industries is conducting research and development on another security system, once again based on the NASA technology.

®Electronic Nose is a registered trademark of Grace Industries, Inc.

Penetrating Fire Extinguisher

Feecon Corporation, Westboro, Massachusetts manufactures fire protection systems and equipment used by airport, municipal and industrial firefighting organizations. One of its products, in production for 10 years, was a bayonet type piercing nozzle used in combating aircraft crash fires; connected to a hose, the nozzle could be thrust through the skin of an airplane, allowing water or chemical sprays to reach the plane's interior. The nozzle worked well on small aircraft with relatively thin aluminum skins but was ineffective on larger, thick-skinned aircraft.

Seeking to add the latter capability, Feecon learned of NASA technology developed for use in the event of a crash landing by the Space Shuttle Orbiter: a fire-extinguisher with a hard, pointed tip that could be rammed through the skin of the Orbiter to dispense chemicals inside the spacecraft. Developed by Kennedy Space Center and engineers of The Boeing Company, the ram-type nozzle can also be used to penetrate metal skins of aircraft, trains and other vehicles or to pierce wood, plasterboard, plastic or metal walls in buildings.

Feecon obtained a NASA license for commercial use of the technology and is now manufacturing and marketing the Cobra Ram Piercing Nozzle, shown being demonstrated at upper right. It is used primarily by airport firefighters to discharge water or chemicals on aircraft fires in such internal areas as cabins, cargo compartments, accessory bays or ducts. The 30-pound, 82-inch long nozzle has a piercing tip of hardened steel at the spray delivery end (left) and an iron ram at the other end. The firefighter grips a rectangular loop with one hand (above) and with the other he forcefully slides the ram along the tube so that the ram energy is transmitted to the piercing tip. The procedure is repeated until penetration is achieved, then a valve is turned to discharge fire extinguishing agents into the interior fire area. The primary advantage of the Cobra Ram is that its design permits the nozzle to be held in one spot during repeated blows of the ram. There is no National Fire Protection Association (NFPA) requirement that airport crash fire trucks carry the piercing nozzle but it is being considered as an NFPA recommendation.

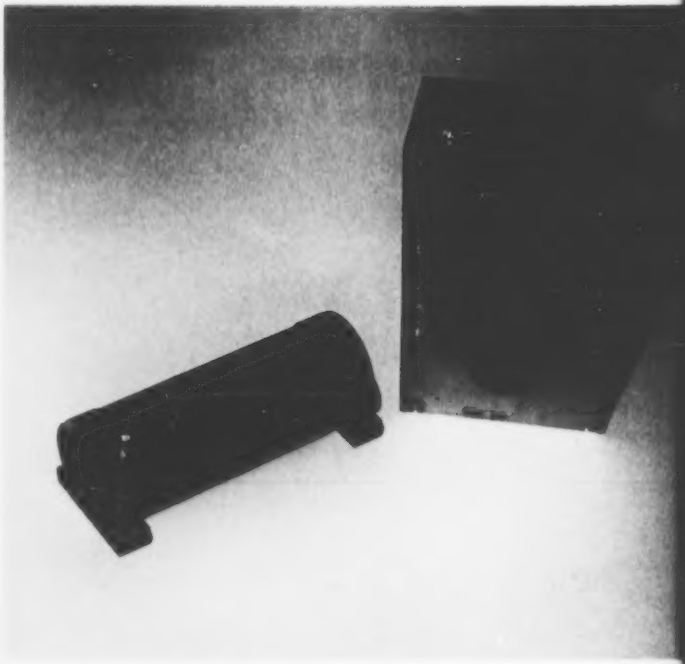
Sonar Locator Systems

The object at left in the photo is a Model 590 UnderwaterAcoustic Beacon, less formally known as a Pinger; the other unit is a Pinger Tester. Developed and manufactured by Burnett Electronics Lab, Incorporated, San Diego, California, the Pinger is an underwater locator device attached to an airplane's flight recorder for recovery of the recorder in the event of a crash. The flight recorder tapes cockpit conversation prior to the crash; its recovery provides clues as to what caused the accident and suggests measures to prevent similar occurrences.

Activated upon immersion in the water, the Pinger's battery-powered transmitter sends omnidirectional signals for as long as 500 hours. The signals are picked up by a receiver on the surface, for example, Burnett's transistorized Model 512 (the company manufactures several types). The Model 512 is designed for use by a diver with SCUBA gear operating from a small surface craft. Lowered over the side of the boat, the sensitive receiver detects Pinger signals and converts them to audible sounds whose strength is directly proportional to the direction and distance from the signal. This provides an initial bearing to the Pinger; the diver then enters the water and swims to the Pinger's location, using the receiver as a hand-held homing system.

Burnett Electronics' underwater sound/search systems trace their lineage to research performed by Langley Research Center and the U.S. Navy in the early 1960s. The Navy had designed a search/locator system for recovery of underwater mines. Langley, with a similar need for locating research sounding rocket payloads parachute-lowered to the ocean., used the Navy design as a departure point for development of an improved system. Langley then contracted with Burnett Electronics to refine the system and supply receivers for NASA and Navy use. Burnett subsequently used the expertise gained in the Langley contract as a base for company-funded development of an advanced line of sonar systems for government and commercial use.

Burnett Electronics now manufactures severall types of Pingers and associated receiving equipment, including deepwater beacons for such research purposes as whale tracking or marking underwatter discoveries, and such commercial uses as spotting wellheads, pipeline junctions and valves in underwater oil production operations. A sophisticated Model 570 beacon sends acoustic signals from depths as low as 20,000 feet to help oil drilling vessels remain directly over a drill hole. A special purpose Pinger is the Model 522, which provides a way for a diver trapped underwater to signal his position to a monitoring team on the surface. In addition to Navy, aircraft, ocean research and other water-related applications, Burnett manufactures ultrasonic listeners that detect gas leaks in refrigeration and air compression systems on trucks and heavy equipment. The company is engaged in research on several new acoustic-sonar systems.



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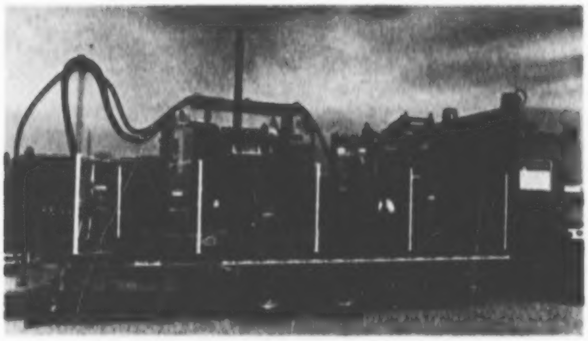
Water Jetting

Water jetting is the use of high pressure, high velocity water directed at a surface to apply an enormous amount of energy in a small area. It is, in effect, a cutting tool, used in such applications as removing granite blocks from quarries or concrete from bridges under repair. Among companies manufacturing water jetting equipment is Hi-Tec, Inc., Milbank, South Dakota; at right is a Hi-Tec trailer-mounted, diesel-powered, automatic water jetting system.

Hi-Tec was spawned as the result of a U.S. Bureau of Mines directive in the late 1970s requiring that the quarry industry find a less noisy method of removing granite from quarries, because existing equipment was so deafening it was considered health-endangering. Dakota Granite Company, also located in Milbank, initiated development of a low-noise water jetting system to meet the Bureau of Mines requirement in its own quarrying operations. The successful development program, directed by company chief engineer Roger Raether, led to formation of Hi-Tec for manufacture of the innovative water jetting systems and equipment that resulted. Raether became president of Hi-Tec and James Stengel, chief executive officer of Dakota Granite, became vice president.

Dakota Granite initially focused on development of the key element of the planned system, a high pressure rotating swivel capable of operating at a pressure of 24,000 pounds per square inch; the company intended to use commercially available hardware for other components of the system. It became apparent, however, that an effective system would require development or redesign of other components, such as self-sealing pumps, nozzles and nozzle holders, high pressure hose protection devices and new pressure sensing and automatic shutdown devices. In the course of an extensive research program, the company benefited from water jetting technology developed by Marshall Space Flight Center to clean and remove material from components of the Space Shuttle's solid rocket boosters in the process of refurbishing the boosters. In the lower photo, a Cincinnati Milacron computer-controlled robot is directing a sharply focused, high pressure water blast spray onto the forward skirt of a solid rocket booster; it is removing an ablative coating that provides thermal protection from the booster in flight.



The Dakota Granite/Hi-Tec effort culminated in development of completely automatic water jetting systems now built and sold by Hi-Tec. One is a quarry machine that cuts rock and granite at a pressure of 19,000 pounds per square inch. Hi-Tec also offers a 12,000 pound per square inch system for removing deteriorated concrete from the surface of bridge decks undergoing reconstruction. Among advantages of Hi-Tec systems cited by the company, in addition to noise levels far below those of earlier equipment, are minimal labor costs, due to automatic operation that requires only occasional adjustment; no dust, because the water spray supresses it; high rates of production; low overall operational cost; and automatic shutdown if any part of the machine malfunctions.

An economical energy storage system leads a representative sampling of aerospace technology applications to energy development, supply and conservation

An Innovation for the Energy Industry

Although the energy crisis of the 1970s has abated, it significantly elevated the cost of energy and thus inspired a continuing quest for better ways of managing energy use. An important part of this quest is finding new and more efficient methods of storing energy. Utility companies, for example, need an economical means of "load leveling"—storing thousands of kilowatts of energy during low demand periods for later use when demand peaks. On a smaller scale, operators of solar electric and wind energy systems must store energy for use at times when sunlight and wind force are not available; storage costs have been a major drawback to widespread employment of such systems, so a low-cost storage technique could hasten their acceptance and substantially increase the national energy supply.

For more than a decade, NASA and the Department of Energy have been investigating a variety of energy storage concepts. One program—called REDOX and developed by Lewis Research Center—advanced to the point where the technology could be transferred to the private sector. Last August, NASA and Standard Oil Company of Ohio (SOHIO) concluded a licensing agreement whereby SOHIO will take over the technology for further development and possible commercialization.

REDOX is a compression of Reduction and Oxidization, a term commonly used in battery technology. The system promises major reductions in the cost of storing electrical energy, long-term reliability and minimal impact on the environment.

The heart of the REDOX system is a series—or "stack"—of flow cells. Chemical energy is converted into electrical energy when two reactant fluids—solutions of chromium chloride and iron chloride—are pumped through the stack. In each flow cell, the fluids are kept apart by a special membrane. Ideally, the membrane prevents reactant ions in one fluid from mixing with reactant ions in the other fluid. However, the membrane allows smaller chlorine and hydrogen ions to pass through freely and transfer electric charge, carrying a flow of electric current through two electrodes.

The electrical energy is withdrawn at external connections to the electrodes. When the electrochemical energy in the fluids is depleted, the system can be recharged by pumping the reactants through the stack again—but with electrical energy supplied by an outside source. The reactants can be used indefinitely. Only a small fraction of the system's energy is consumed in operating the circulating pumps; 75 percent of the energy used to charge the system is returned on discharge, an efficiency comparable to conventional batteries.

But REDOX offers a number of advantages over conventional batteries. The lead-acid battery in use for more than a century has a major drawback: during recharge, the solid lead compounds on the electrodes do not always return to their previously charged sites and some lead solids fall away from the electrodes. This loss of active material causes gradual battery deterioration and ultimately the battery is useless. In REDOX, no solid compounds are formed, hence there is no deterioration. The life-limiting component is the membrane, whose useful life—based on extensive testing by Lewis Research Center—is estimated at 20 to 30 years.

A major advantage of REDOX is its flexibility: the stack and the storage tanks can be sized independently to yield the best system characteristics for a given application. Stack size depends on the desired power (watts) to be delivered at any one time. Storage tanks are sized for the energy (watt-hours) needed for the time between recharge cycles, which can be days, weeks or even months. This capability for independent sizing means potentially longer storage times, greater energy storage levels and lower storage costs.

Lewis' REDOX system was demonstrated by frequent operation of a portable 200-watt unit. The system can be scaled up to the kilowatt range to the benefit of solar electric and wind energy systems. Fairly small, these systems are usually isolated from utility power lines. REDOX promises a one-to-one replacement of presently-used lead acid batteries at greatly reduced cost—perhaps as low as one-third of current outlays.

Scaled up to the megawatt range, REDOX could effect large savings for utilities by providing an energy reservoir to be called upon during periods of maximum consumption. Economical, efficient REDOX storage could obviate the need for relatively expensive, less efficient standby generating equipment and also eliminate the use of high quality levels for these generators. An energy storage system like REDOX would be of greatest value to utilities that generate power from coal or nuclear energy; such units operate most efficiently at a steady output and they produce the cheapest electricity other than hydroelectric systems. REDOX could also help small metropolitan systems that purchase much of their power at complex rates dependent upon peak demand; by buying power at offpeak rates and storing it, they could realize substantial cost reductions.

Dr. Glenn L. Brown, SOHIO vice president of technology and planning, voiced his company's optimism about the potential of REDOX in comparison with lead-acid battery storage, in particular its longer life and lower construction/maintenance costs. "Although additional basic research and development work will be required," he said, "SOHIO believes this technology may help to reduce America's energy costs at some point in the future."

This is a 200-watt demonstration unit of a unique, NASA-developed energy storage system known as REDOX, which—scaled up to much higher power levels—promises major reductions in the cost of storing electrical energy.

Thermionic Energy

In 1962, in the fledgling days of space flight, NASA teamed with the Atomic Energy Commission (AEC) to form a joint research and development organization known as the Space Nuclear Systems Office (SNSO), no longer extant. SNSO's job was to focus R&D activity in a specialized area: the use of nuclear energy for high power, high temperature space applications. Involved in the effort, in addition to AEC, where NASA's Lewis Research Center and Jet Propulsion Laboratory, Navy and Air Force research units, Los Alamos National Laboratory and a number of contractors.

One of the technologies SNSO sought to advance was thermionic energy conversion, the production of energy from a heat source—in this case, a nuclear source. SNSO contracted with a then-small company known as Thermo Electron Corporation (TECo), Waltham, Massachusetts, which had been formed a few years earlier specifically to develop thermionic energy conversion technology. Because thermionic conversion operates in high temperature applications, TECo's work for SNSO involved development of refractory metals—metals with high melting points, such as molybdenum, tungsten and tantalum. TECo developed processes for these difficult-to-work metals in the areas of machining, bonding, forging and swaging (tapering a rod or tube).

The expertise thus acquired triggered a major expansion of TECo. Broad interest in the company's metalworking abilities resulted in the creation—in 1964—of a Metals Division, which received a contract from Oak Ridge National Laboratories to develop further its machining and fabricating techniques. TECo's reputation for precision machining, hot metalworking and bonding spread from the U.S. to Japan, England and Italy.

TECo is today noted for its ability to produce many parts other companies would not attempt to make. The photo at left shows a sampling of Metals Division parts made of molybdenum, tungsten and other specialty alloys. At left below a technician is monitoring a numerical-control machining center that enables manufacture of precision parts in high volume. Below, Metals Division electrical discharge machines are used in production of military electronics systems, one of the division's largest areas of activity. TECo's know-how in working exotic metals resulted in a capability to manufacture bone implants, such as artificial hips made of cobalt chrome. The company's expertise in working tantalum has been applied to manufacture of heart pacemakers. The Metals Division has grown from six people in 1964 to 130 today, but it is a small part of what has become a major U.S. company with sales on the order of $250 million annually. Company officials acknowledge that TECo's expertise and reputation acquired in work for SNSO provided the basic impetus for this large-scale expansion.

Energy Saver

NASA's *Tech Briefs*, a quarterly publication that reports on new technologies available for transfer, has inspired many a spinoff. A recent example is a new commercial energy-saving product developed by engineers of Harris Corporation's Semiconductor Sector, Melbourne, Florida as an extension of an innovation described in *Tech Briefs*.

As part of its energy conservation research in support of the Department of Energy, Marshall Space Flight Center (MSFC) sought a means of curbing power wastage caused by the fact that alternating current motors operate at a fixed voltage. The fixed voltage is what motors need to handle the heaviest loads they are designed to carry, but a motor does not usually operate at full load condition; even when it is idling, the motor is still drawing full-load voltage, causing great power wastage. MSFC engineer Frank Nola developed a device—called the Power Factor Controller—that matches voltage with the motor's need. When it senses a light load, it cuts the voltage to the minimum required, thus effecting large-scale energy savings.

Harris Semiconductor's Peter Shackle, manager of the High Voltage Products Section, and Robert S. Pospisil, lead engineer, read details of the Nola invention in *Tech Briefs* and used the technology as a departure point for a related innovation: an integrated circuit intended to reduce onto one chip most of the circuitry of the Marshall Power Factor Controller for single phase induction motors. Such motors—typically used to power drill presses, sewing machines, conveyor belts, washing machines, dryers and dishwashers—are notoriously inefficient when lightly loaded. The Harris Semiconductor remedy is the HV-1000 Induction Motor Energy Saver (IMES). Heart of the IMES is the tiny silicon chip pictured at left, which connects directly to an alternating current line. IMES continuously monitors the motor and provides it with electrical energy computed by the chip to be the precise voltage required to drive the motor at optimum efficiency. In the photo below, a Harris Semiconductor engineer monitors power measurement equipment during operation of a drill press equipped with the HV-1000 controller. The IMES-equipped drill press uses less than 79 watts; the same drill without the HV-1000 would draw 160 watts.

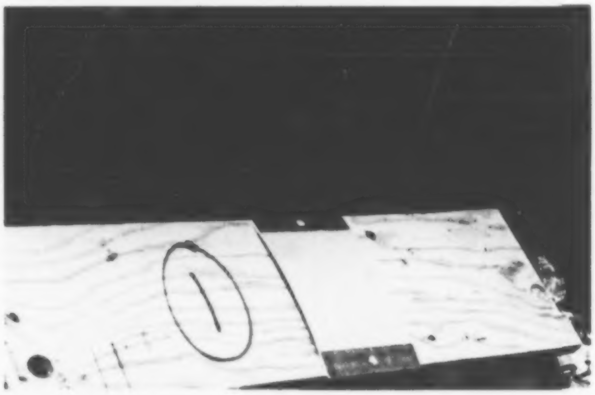
Train Analysis

The U.S. railroads have an annual operating budget on the order of $25 billion, a significant portion of it expended on items related to the "running resistance" of trains, or the combined resistance induced by aerodynamic drag and mechanical friction. Overcoming running resistance involves fuel costs amounting to about 16 percent of the operating budget and maintenance/replacement costs for wheels and rails are of similar magnitude.

To decrease running resistance, it is first necessary to quantify it by full-scale train testing, then separate it into its two components—aerodynamic drag and rolling resistance—in order to develop a thorough understanding of total running resistance toward designing more fuel efficient locomotives, cars and components. Such information is essential to an economic analysis that must be conducted to determine the viability of proposed design changes. But information on running resistance is hard to come by; existing methods are felt to be insufficiently accurate. Seeking a better approach, one railroad—The Atchison, Topeka and Santa Fe Railway Company (AT&SF), Topeka, Kansas—is looking into the potential of an aerospace-originated technique for obtaining improved understanding of the characteristics of train running resistance.

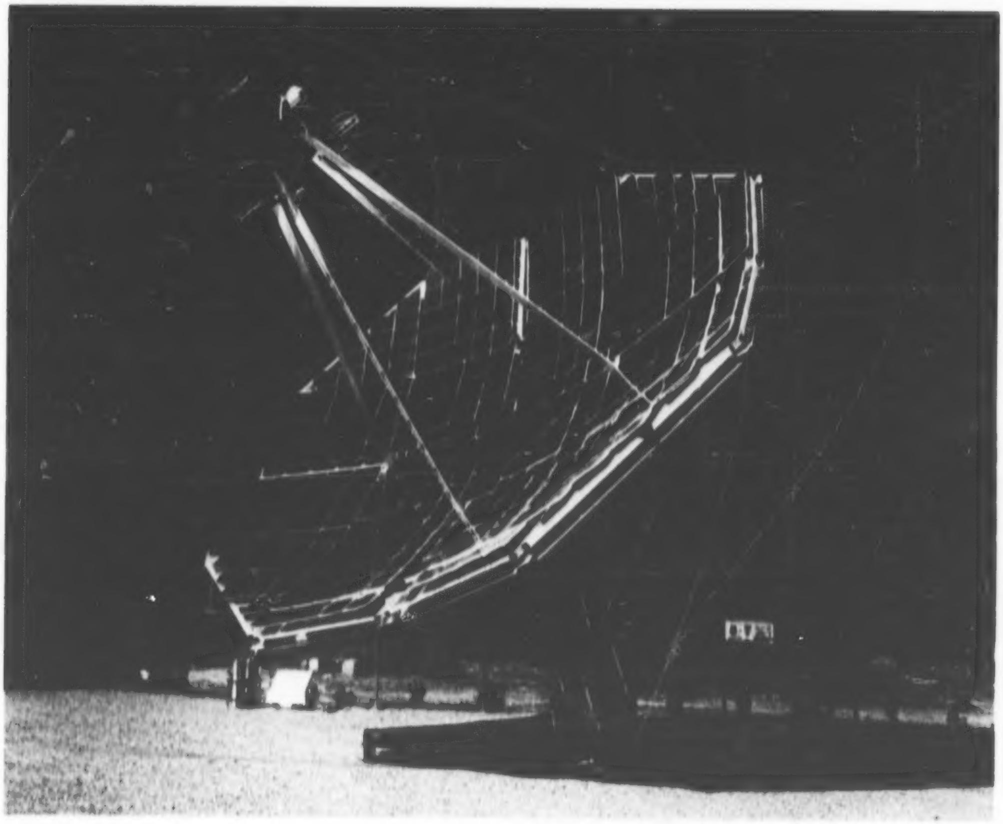
AT&SF, primarily a freight mover operating on a 12,500-mile track system, owns approximately 75,000 freight cars and 2,000 diesel electric locomotives. The company uses more than 400 million gallons of fuel a year at a cost of about one dollar per gallon, so even a small percentage reduction would mean significant savings. Over the past several years, AT&SF has undertaken many fuel conservation measures, among them reduced train speed, train handling improvements, equipment design and improved track maintenance standards. The company has also sponsored aerodynamic computer modeling of trains and small-scale wind tunnel tests.

Looking for ways to expand its cost-cutting program, AT&SF became interested in the NASA-developed Coast-Down Technique, which combines the aerospace technology of flight vehicle trajectory analysis with the use of a modern high-speed computer. This technique offers reduced complexity in full-scale testing of rolling stock and promises accurate analysis of a variety of engineering considerations—such as locomotive, car and track design—and operating conditions—such as speed and train configuration. AT&SF entered into a joint agreement with NASA wherein the railroad provided the track, trains, crews and railway survey measurements, while Jet Propulsion Laboratory (JPL) demonstrated the applicability of the Coast-Down Technique. Funding for JPL's effort was provided by NASA's Technology Utilization Office.



The demonstration was conducted over a five-mile segment of straight and near-level track near Pomona, Kansas; a portion of the test area is shown at upper left, opposite page. Several different train configurations were tested, including a base train (middle photo, opposite page); a high-drag train composed of alternating boxcars and flatcars (lower photo, opposite page); a heavily loaded train; two short trains of different load weights; and the locomotive alone. To get the "distance history" of a coasting train, JPL researchers measured distance/time by using a system of reflective targets mounted on the ties every 1,200 feet; one is shown at left. A sensor near the rear step of the locomotive (bottom left) noted the time of passage over each target and reported the information to a computer (bottom right) located inside the test car. Relative wind was recorded by equipment on the test car and absolute wind was determined by an anemometer at wayside.

Distance history data for each of 32 test runs was converted to an accurate "speed history." Test data was computer-processed to obtain total running resistance for each of the various train configurations; running resistance was subsequently separated into the aerodynamic drag and rolling resistance components. JPL analysts reported that the Coast-Down Technique is a practical method of determining the characteristics of running resistance to an accuracy of about one percent, due in part to the absence of data-degrading instrumentation noise encountered in other methods. The field tests were carried out in 1983 and, after several months of data reduction and analysis, JPL submitted its final report to AT&SF last year for further evaluation by the railroad company.



Solar Generator

NASA's Jet Propulsion Laboratory (JPL) has played a leading role in several facets of the national solar energy development program, a cooperative effort of NASA and the Department of Energy (DoE). One JPL project (1979–81) involved development of a test bed Solar Parabolic Dish-Stirling Engine System Module. The "dish" was a mirrored solar concentrator that reflected solar heat to an engine/generator, which converted the heat to electricity. The generator was an adaptation of a Stirling external combustion engine, developed in part with NASA/DoE funding and in part with private funding by United Stirling AB, Malmo, Sweden.

Successfully tested at Edwards Air Force Base, California, the JPL/United Stirling test system provided a departure point for a more advanced Vanguard I dish-Stirling module program initiated in 1982. Shown in the accompanying photo, the Vanguard I module is a commercial prototype erected by Advanco Corporation, El Segundo, California at Southern California Edison (SCE) Company's Santa Rosa Substation in Rancho Mirage, California; the program is jointly funded by Advanco, United Stirling SCE and DoE. The module combines the JPL mirrored concentrator technology, an advanced Stirling Solar II engine/generator, and a low-cost microprocessor-controlled parabolic dish developed by Advanco; 36 feet in diameter, the dish automatically tracks the Sun throughout the daylight hours, producing solar heat of more than 1,300 degrees Fahrenheit to generate 25 kilowatts. Tests began in 1984; they were to continue for a minimum of 12 months with the option of extending the test work and expanding the scope of the project. In one of the initial tests, Vanguard I accomplished a record 28 percent sunlight-to-electricity conversion efficiency. If tests prove the system effective and reliable, Advanco and SCE plan to construct a multi-module generating plant that would sell electricity to local utilities. They are considering large arrays of up to 1,600 modules generating 30,000 kilowatts.

In a related development, United Stirling has signed an agreement with McDonnell Douglas Corporation to develop, manufacture and market a similar 25 kilowatt module employing a Stirling Power Conversion Unit, a derivative of the Solar II engine, and a dish concentrator designed by McDonnell Douglas. The partnership plans generating facilities capable of producing 10,000 to 50,000 kilowatts by combining 400 to 2,000 modules.

Subsurface Mapping

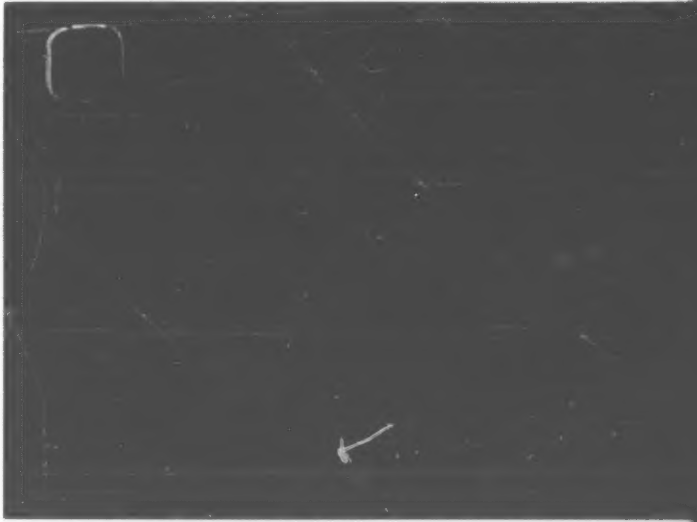
The helicopter pictured at right, operated by AirBorne Pipeline Services, Inc., Redmond, Washington, is an aerial mapping platform whose on board equipment can "see" underground to aid more economical pipeline construction and monitoring. Boom-mounted sensors provide input for electromagnetic sounding systems that produce computer-processed views of subsurface features.

The company's Geologic Sounder is a fast, cost effective method of obtaining accurate geologic surveys down to 650 feet below ground. It has been used in the U.S. and Canada for locating and mapping coal seam depths, mineral bearing deposits and boulder/bedrock formations in placer gold fields.

A companion Geotechnic Sounder, accurate to 82 feet, is a tool for pipeline preconstruction surveys; for example, if the subsurface map shows bedrock or ice, planners can alter the path of the pipeline, avoiding expensive surprises during construction. Capable of covering 250 miles a day, the system offers quick, inexpensive data collection for use in establishing target areas for sinking boreholes or for interpolating between boreholes. It is also used for mapping—even through concrete or asphalt—existing underground pipelines, telephone cables and power lines. The lower illustration shows a computer-created image based on Geotechnic Sounder data. The pipe is red-orange, the pipe coating yellow; other features shown are silts (dark blue) and sands (light blue); the orange stack above ground is an air duct. The system has additional application in mapping subsurface conditions of interest to environmental engineers, such as polluted soils or aquifers containing heavy metals, acids or petroleum.

Other services offered by AirBorne Pipeline include monitoring oil and gas pipelines for early signs of leaks or corrosion, matters of prime concern to pipeline operators because of high pipe replacement costs, potential product loss and environmental considerations. The company's AirBorne Cathodic Protection Monitoring System, which studies the effectiveness of corrosion-prevention measures, and the Hydrocarbon Detection System, used for leak detection, offer less expensive and far more rapid alternatives to traditional pipeline inspection by walking ground crews.

The helicopter-based systems incorporate NASA technology in several areas. Ames Research Center, active in research on sensors for Earth resources observation programs, provided technology used in development of the sounding instruments and guidance for mounting the instruments on composite helicopter booms. Quality control measures were based on Johnson Space Center quality control manuals developed for NASA's Apollo and Space Shuttle programs. Ames, Johnson, and Goddard Space Flight Center all assisted with technical advice on mission planning and program management. All of AirBorne Pipeline's systems were first developed by Applied Science, Inc., a subsidiary of Northwest Energy Company, Salt Lake City, Utah, under the direction of Dr. Michael E. Stamm, then vice president of Applied Science. That company was acquired by AirBorne Pipeline last year and Dr. Stamm became president of the latter firm.



A system for drying agricultural crops and protecting them from insects typifies spinoffs in the fields of resources management and environmental control

Space Chambers for Crop Treatment

During a 1973 fire at the U.S. Government Records Center in St. Louis, Missouri, millions of documents were water-soaked by firefighting efforts. In the same city, McDonnell Douglas Corporation was operating large vacuum chambers to test spacecraft and components under the airless conditions they would encounter in space. As the government archivists pondered what to do about their irreplaceable records, a McDonnell Douglas engineer suggested an answer: dry them in a vacuum chamber, whose gentle microwave heating would leave them undamaged.

McDonnell Douglas undertook the job of developing a process for drying the records. It involved subjecting them to heat produced by microwave energy in an atmosphere of reduced pressure within the space chamber; the near-vacuum would lower the vaporizing point of the water in the documents, therefore drying temperature would be lower, allowing the papers to dry uniformly without curling or charring. It worked; the government was able to reclaim more than four million documents.

That started a chain of spinoff applications. McDonnell Douglas patented the drying process and started a sideline business of using its four vacuum chambers, when they were not engaged in space research, to dry valued articles soaked during floods and fires.

Looking to the broader potential of the drying process, McDonnell Douglas came up with a spinoff from the spinoff: a rapid, efficient method of drying agricultural crops by means of a system called MIVAC™, a compression of Microwave Vacuum Drying System. In 1977, when the quest for new ways of conserving energy was in full swing, McDonnell Douglas won a contract from the Department of Energy for fabrication of a small experimental unit to demonstrate MIVAC's potential for reducing the great amounts of energy required for drying harvested crops; drying is an essential first step in crop processing, a means of making crops easier to ship and store. Most farmers use equipment powered by oil or natural gas to blow heated air over the produce. MIVAC, a distant cousin of the home microwave oven, dries more efficiently by means of electrically generated microwaves introduced to a crop-containing vacuum chamber; the microwaves remove moisture from the product very rapidly, reducing the time power is needed. Additionally, the low pressure atmosphere permits effective crop drying at much lower than customary temperatures, further reducing the energy requirement.

McDonnell Douglas teamed with Aeroglide® Corporation, Raleigh, North Carolina, a major manufacturer of conventional drying equipment, to construct the experimental MIVAC. Built at a U.S.

Shown above is the first commercial scale MIVAC plant, a microwave/vacuum crop drying system that evolved from space simulation technology. The pilot MIVAC, located in Guntersville, Alabama, is operated by Continental Grain Company; the spinoff system was developed by McDonnell Douglas Corporation.

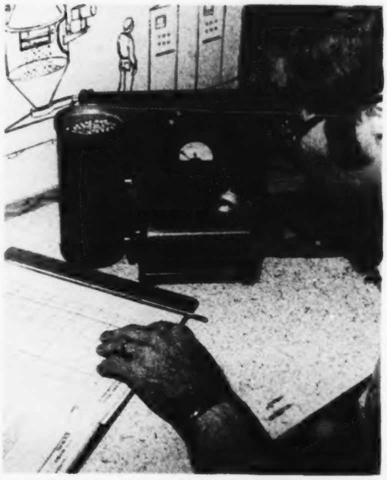
Department of Agriculture (USDA) station at Tifton, Georgia, the system demonstrated that MIVAC's promise went far beyond energy conservation. A big plus, its developers say, is that it does a better job of drying more easily damaged crops—rice, for instance. The hot-air blowing method may harden the outer coating, making it difficult for moisture to escape, causing cracked grains and loss of quality. MIVAC heats rice—and other products—evenly from the inside out, without hardening or damage. The system is environmentally clean; it has no polluting exhaust, its electric motors are virtually silent and, because MIVAC does not employ hot air blowers as do conventional dryers, the chance of fire from the grain's dust and chaff is reduced. Change of product entails no change of equipment; at Tifton, the system successfully dried wheat, rice, peanuts, soybeans, corn, pecans, prunes and raisins.

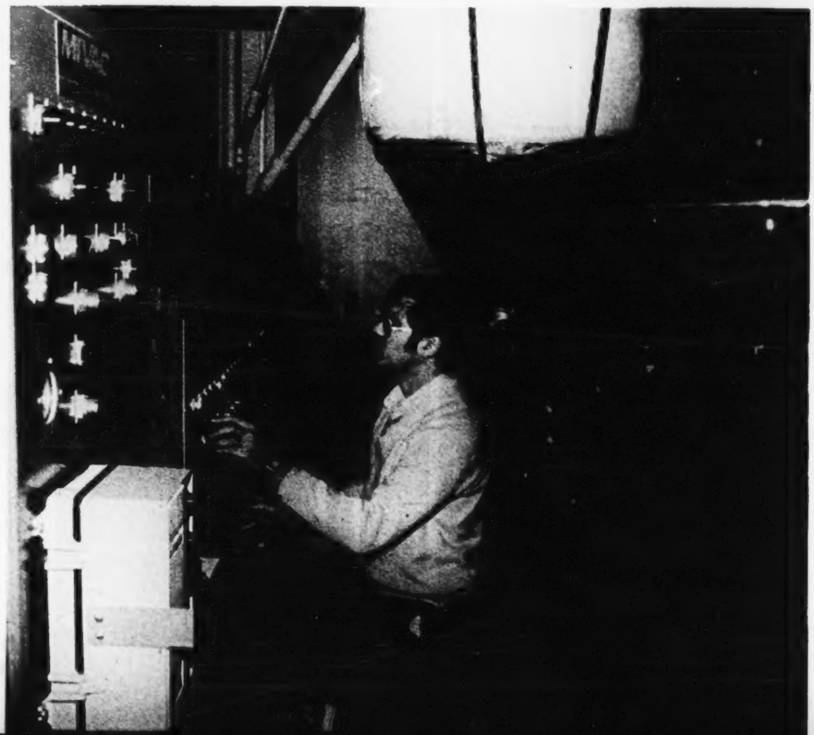
The Tifton unit—still being operated by the USDA—demonstrated the practicality of microwave/vacuum drying for a wide range of agricultural products and encouraged McDonnell Douglas and Aeroglide to take the next step: developing and commercializing a larger-scale MIVAC. Under a cooperative agreement, McDonnell Douglas handles MIVAC design and engineering, Aeroglide is responsible for marketing and manufacturing.

Under this agreement, the companies built the first commercial-scale MIVAC dryer at a plant operated by World Processing Division of Continental Grain Company in Guntersville, Alabama, where soybeans are processed into high protein animal feed and vegetable oil. Where the original demonstrator handled about 10 bushels an hour, the commercial prototype is capable of processing five tons of soybeans hourly—and that capacity can be doubled or trebled without redesigning the unit. Since it began operation in 1983, the Guntersville MIVAC has demonstrated significant reductions in energy use and additional savings because microwave drying eliminates certain steps necessary in conventional processing.

Last year, McDonnell Douglas advanced the technology one more step when—with the cooperation of the USDA—it developed a microwave sanitation process for use in MIVAC which kills insects and their larvae and eggs living in dried grains. Stored crops currently are sanitized with chemicals or nuclear radiation, both of which leave a contaminating residue that is carried into the processed food product; MIVAC leaves no residue. Unlike the MIVAC continuous drying process, sanitizing employs short bursts of intense microwaves that kill the insects but do not char the crop. McDonnell Douglas and Aeroglide are exploring the possibility of marketing the process as an alternative method of deinfesting grain.

MIVAC is designed to dry crops more efficiently than the hot-air dryers now in use. Microwaves heat the product evenly at low temperature, removing moisture without damaging the crop. At right, a technician is testing a crop sample on a moisture meter to determine the correct drying time for a MIVAC run; below, he is adjusting the controls accordingly.





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Atmospheric Radiation Study

Atmospheric and Environmental Research, Inc. (AER), Cambridge, Massachusetts is a privately-owned research company that provides a variety of atmospheric science services to government and industrial customers. The company's remote sensing group has developed a model that simulates the sensitivity of satellite-measured solar radiation to changes in relative humidity and wind speed near the ocean surface. The model is used to support meteorological analyses and to evaluate the use of satellites for determining the extent to which marine aerosols—tiny solid particles or liquid droplets—in the atmosphere reduce the range of optical instruments; it also provides real-time predictions on the possibly reduced capability of optical communications equipment in the ocean near-surface environment. The model was developed under contract to the Office of Naval Research; for the study, AER used satellite data supplied by the Defense Meteorological Satellite Program spacecraft pictured.

During the project, AER used a software package originally developed by Goddard Space Flight Center for analyzing data from NASA environmental satellites. Called RADTMO (Radiative Transfer Models), the package is a set of programs that compute scattered atmospheric radiation caused by aerosols. RADTMO was supplied to AER by the Computer Software Management and Information Center (COSMIC)®, a NASA dissemination center that routinely makes available to customers government developed computer programs that have potential for secondary application.

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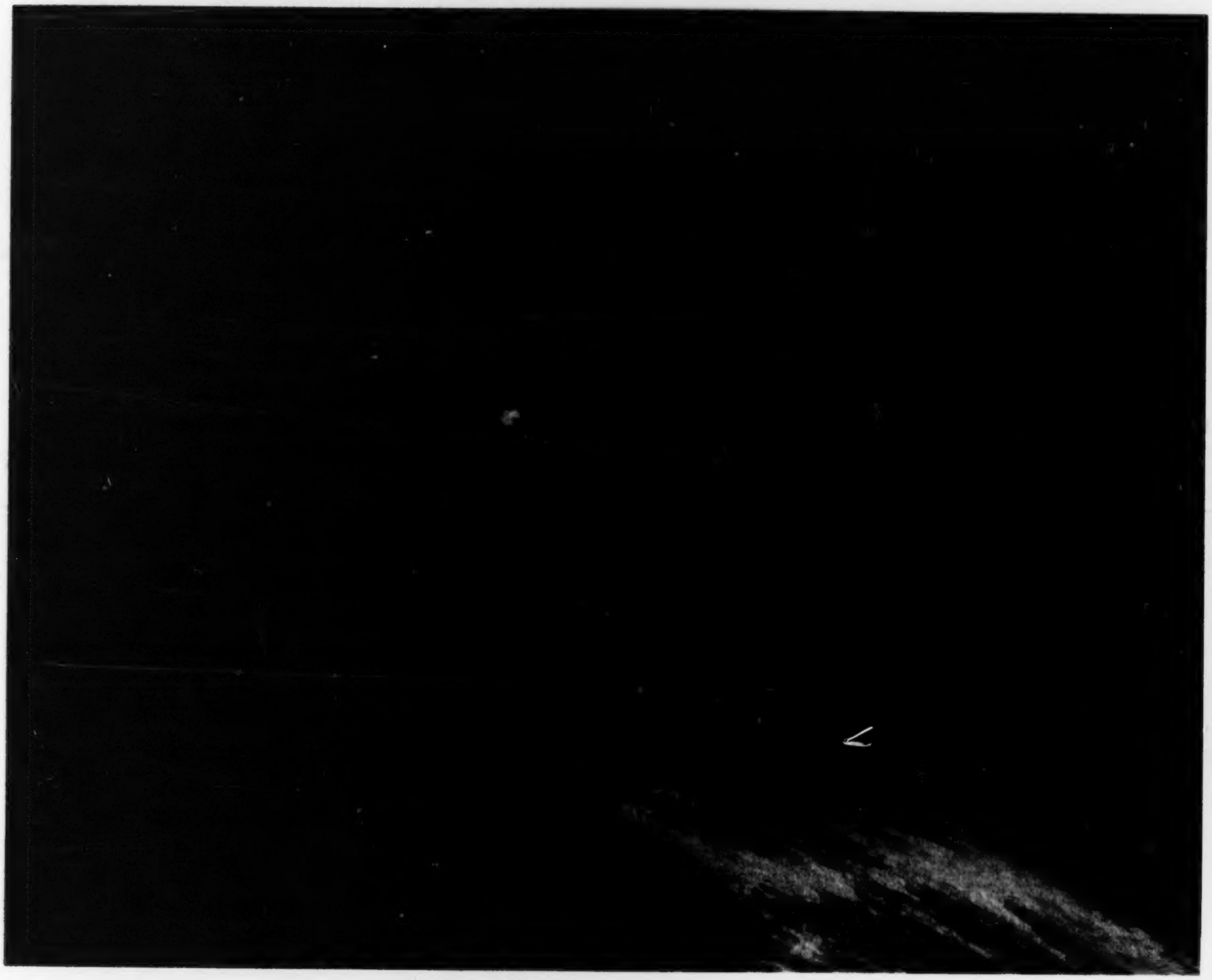
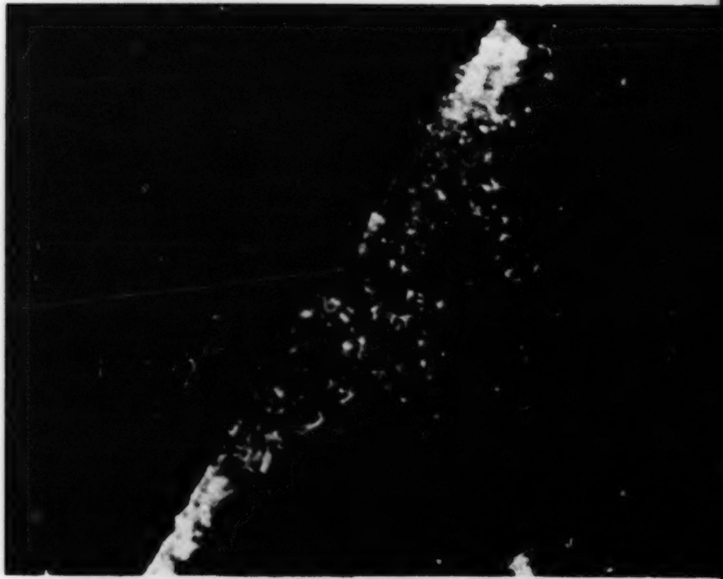


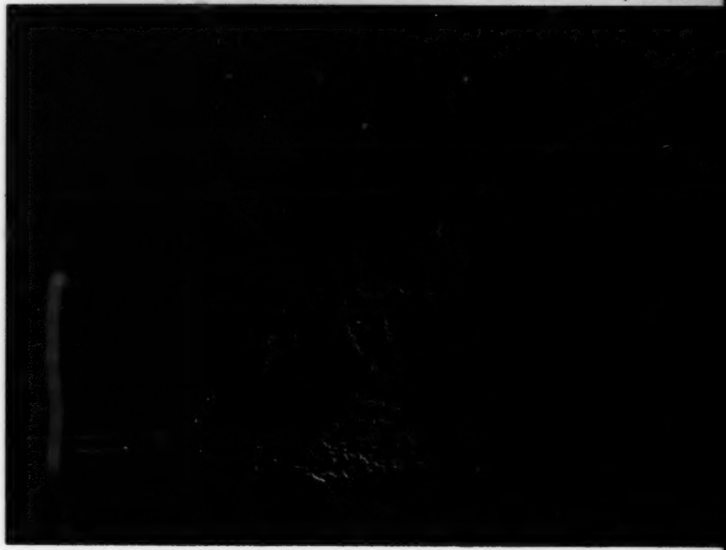
Urban Expansion Study

A matter of concern all over the world is the degree to which urban expansion is encroaching into valuable farmland. It is of particular interest in Egypt's Nile River valley and delta, where agricultural expansion is limited by the surrounding desert. To study how urban growth is affecting the Nile area, the Egyptian Ministry of Development awarded a contract—financed by the U.S. Agency for International Development—to Planning and Development Collaborative International (PADCO), Washington, D.C. NASA's Technology Application Center (TAC) at the University of New Mexico, Albuquerque, assisted PADCO by providing survey maps and area measurements derived from computer processing of data from a Landsat Earth resources satellite.

The study group selected a six-year period from 1972 to 1978 as a basis for illustrating urban expansion in Egypt. Using the image processing system at TAC and a NASA-developed software package called ELAS, TAC classified raw Landsat data covering 21 Egyptian governorates within the Nile valley and delta. At upper right is a raw data image of the delta area around Alexandria. It shows a variety of color-coded features which were computer-processed and grouped into four basic categories: urban land, desert, agricultural land and water. A resulting classification image is shown at lower right; red is urban area, green is vegetated agricultural land, brown is desert and blue is water.

Similar classifications were made for all 21 of the governorates, using Landsat tapes from 1972 and 1978. For each governorate, classifications for the two dates were merged and computer-compared to form another image detailing urban expansion alone. The final products were maps and tables for the four classifications, by governorate or city in 1972 and 1978, and data showing the changes in urban, desert and agricultural acreages that had occurred between the two dates. The results were spot checked by PADCO crews on the ground and reliable correlations were found. Due to an almost complete lack of aerial photos for the dates encompassed, the study could not have been accomplished without Landsat data and the NASA software.



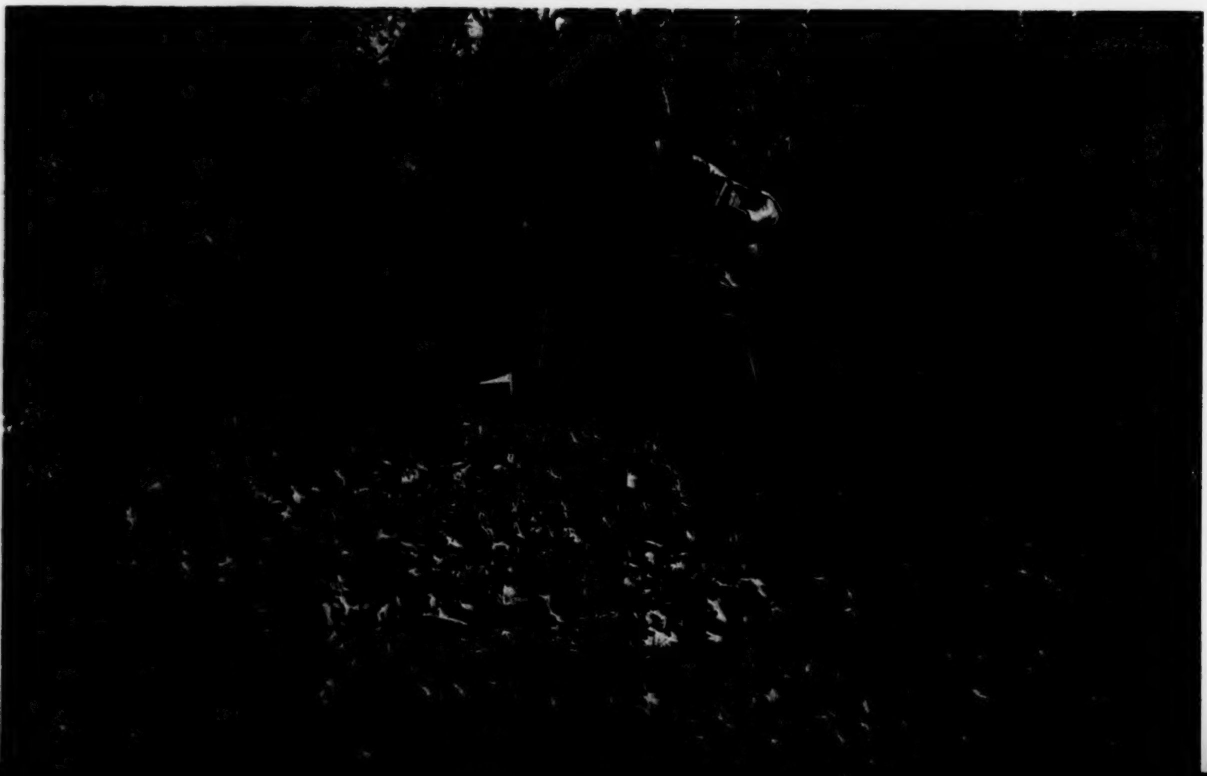


Soil/Rock Analyzer

For several years beginning in 1975, NASA operated two Viking Lander spacecraft on the surface of Mars. Built by Martin Marietta Denver Aerospace, each of the Landers carried more than a dozen instruments for photographing and investigating the Martian surface. One, developed by Martin Marietta under contract to Langley Research Center, was an x-ray fluorescence spectrometer that automatically analyzed the planet's soil and rocks. A redesigned version of that system is now being marketed commercially for use in detecting and analyzing metal and mineral elements. Known as the Aurora ATX-100, it is being manufactured by Aurora Tech Incorporated, North Salt Lake, Utah, under a licensing agreement with Martin Marietta.

The system operates on the principle that different elements emit different x-ray energies. Irradiation by radioisotopes causes a sample to emit x-rays at various energies characteristic of the elements in the sample. The spectrometer then measures the energy emissions as a means of determining what elements and in what percentages the sample contains. The Aurora ATX-100 (top photo) offers self-contained power, an oscilloscope, a liquid crystal readout and a multichannel spectrum analyzer; it can complete an analysis in about 30 seconds. With its batteries, it weighs only 17 pounds, permitting field geologists to make on-the-spot determinations of rock and soil compositions (below) without having to haul loads of samples back to a laboratory.

Other applications include surface and subsurface mineral exploration, pollution monitoring, chemical and mineral industrial process control, analysis of concrete structures and educational demonstrations of x-ray techniques. Last year, Aurora Tech received approval from the State of Utah and the Nuclear Regulatory Commission to sell the radioisotopic unit and made the first deliveries of the system. With a solid backlog of orders and a capability for producing 500 units a month, Aurora Tech is now setting up distributorships abroad. The company is also conducting research and development toward additional applications.

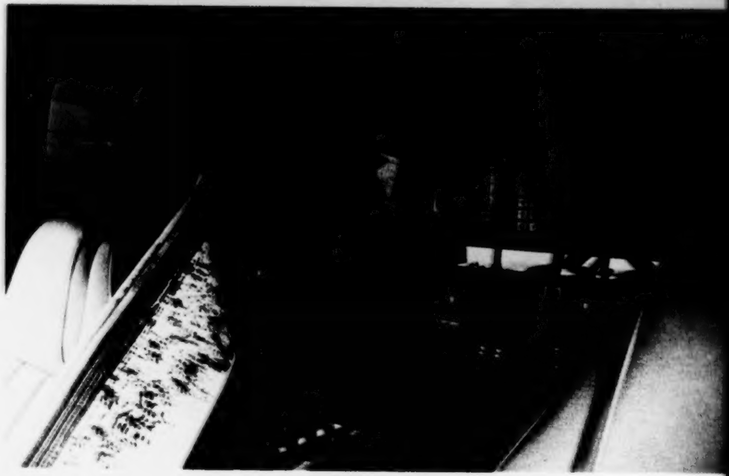


Soil Surveys

Accurate soil surveys are necessary for soil conservation measures, determining building sites, selecting park locations, siting sewage plants and a variety of other reasons. The traditional method of surveying requires auger boring into the ground to obtain subsurface soil samples for classification, a slow and fatiguing process since a typical survey might require hundreds of depth measurements. The U.S. Department of Agriculture's Soil Conservation Service (SCS) is now employing an easier and faster method, developed in cooperation with NASA, that involves use of ground penetrating radar to produce subsurface graphs for interpretation by soil scientists.

At upper right, SCS specialists are surveying an area in Florida. The radar antenna (foreground) is pulled by a four-wheel-drive vehicle along a transect line, a straight line across the surface where normally many borings would be made. As it moves along the transect line at about five miles per hour, the antenna transmits radio waves downward that are reflected back to the antenna when they strike layers—soil, rock, water, man-made objects—of different electromagnetic properties. The antenna relays the reflected pulses to a graphic recorder mounted in the vehicle. The system analyzes the data and produces images on the recorder of subsurface "interfaces," areas where two different types of features meet; the recorder and the radar controls are pictured in the middle photo. In the lower photo, SCS soil scientists examine the recorder's printout; the information does not entirely eliminate the need to dig holes, but only a few are required to double-check the radar's findings. The radar can penetrate to depths of seven to eight feet routinely; in some types of soil it can reach 30 feet or more.

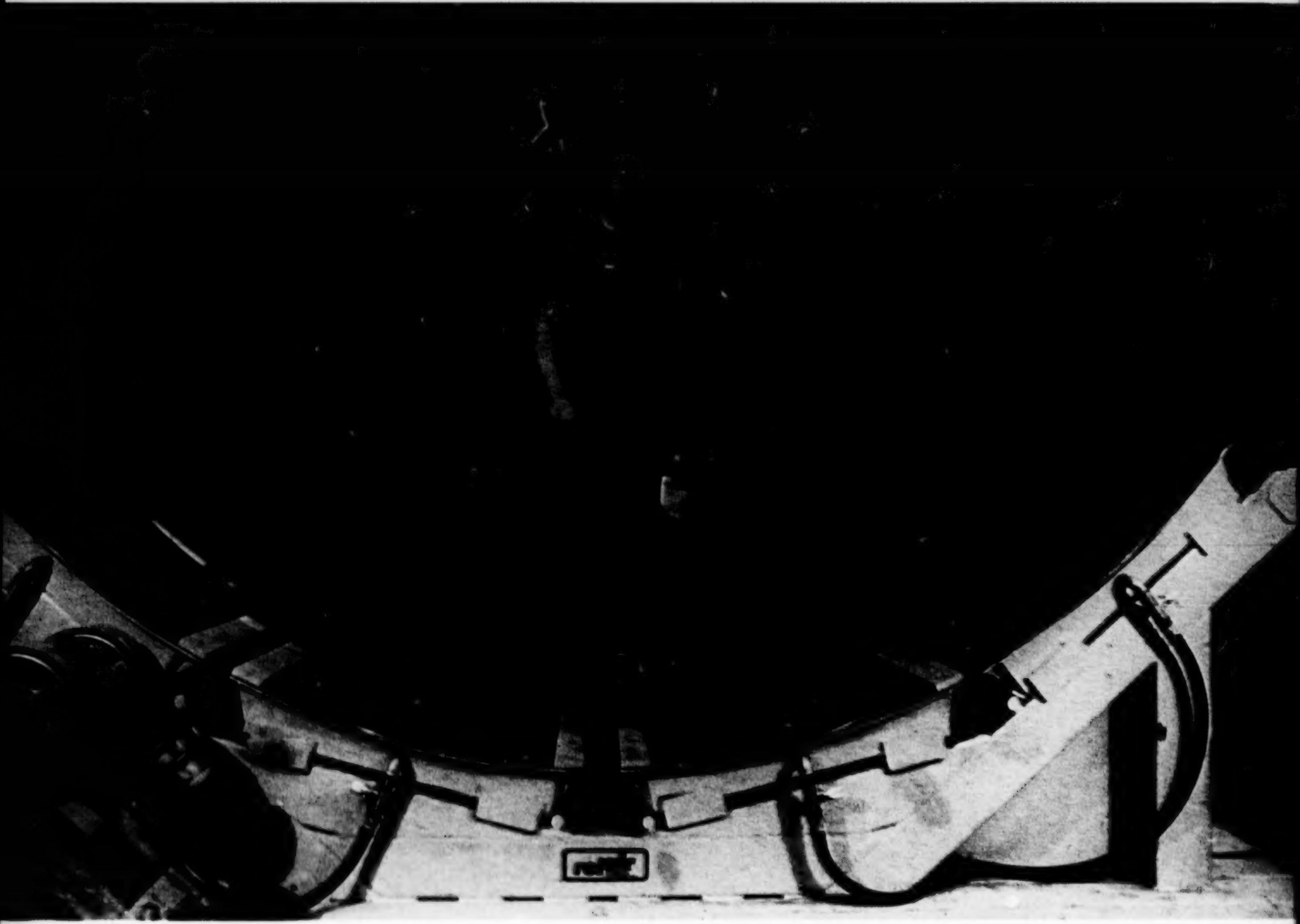
NASA's work in the cooperative project with SCS was performed by Kennedy Space Center (KSC), which studied a number of options to circumvent the limitations of earlier methods of soil surveying—for example, sonar, gravity techniques and geophysical sounding devices. KSC's investigation concluded that ground penetrating radar offered the most advantageous way of obtaining continuous real-time subsurface observations. KSC's study was followed by comprehensive field testing in Florida, conducted jointly by NASA, SCS and Technos Inc., Miami, Florida. The radar system, manufactured by Geophysical Survey Systems, Inc., was purchased by SCS for operational use, initially in Florida; its successful operation in several Florida projects led to purchase of a second unit.



Transportation By Air— On the Ground

Among a sampling of spinoffs in manufacturing technology and industrial productivity is a line of air flotation systems for moving heavy loads

At its Bacchus Works in Magna, Utah, Hercules Incorporated is building advanced filament-wound casings for the Space Shuttle's solid rocket motors. Use of the filament winding technique and graphite composite material sharply reduces the weight of the rocket motors, hence increases the amount of payload that can be boosted to orbit. To be introduced to Shuttle operations next year, the 115-foot cases are 32 tons lighter than the steel cases now in use—



but they are nonetheless large and heavy, built in segments 12 feet in diameter and 20 to 27 feet long. In the course of construction, these segments must be moved from place to place. Such movement is easily accomplished by means of a spinoff Rolair air flotation system, an outgrowth of air bearing technology developed by NASA and General Motors Corporation.

The need for this technology arose during development—in the early 1960s—of the mammoth Saturn V booster for Apollo lunar missions, the largest vehicle ever flown in the free world. The 364-foot superbooster was, of course, built in segments but some of the segments weighed more than 100,000 pounds—and they had to be moved during construction and assembly.

In 1963, Marshall Space Flight Center, Saturn V program manager, contracted with General Motors' Defense Research Laboratory for design, fabrication and test of an air bearing system that would facilitate movement of heavy Saturn V components. The core of the system was an air flotation device earlier invented by General Motors; its use in the Marshall development was the first large scale application of the technology.

The basic idea of the air bearing system is to separate the load from the ground by a thin cushion of air, virtually eliminating surface friction and enabling easy movement of heavy loads in any direction. The air bearings are elastic diaphragms inflated with air. During their operation, controlled

At a Hercules Incorporated plant in Utah, multi-ton rocket cases are moved easily by a Rolair system that virtually eliminates friction between the load carrying pallet and the plant floor. The 12-foot diameter cases "float" on air bearings, shown in closeup at right.

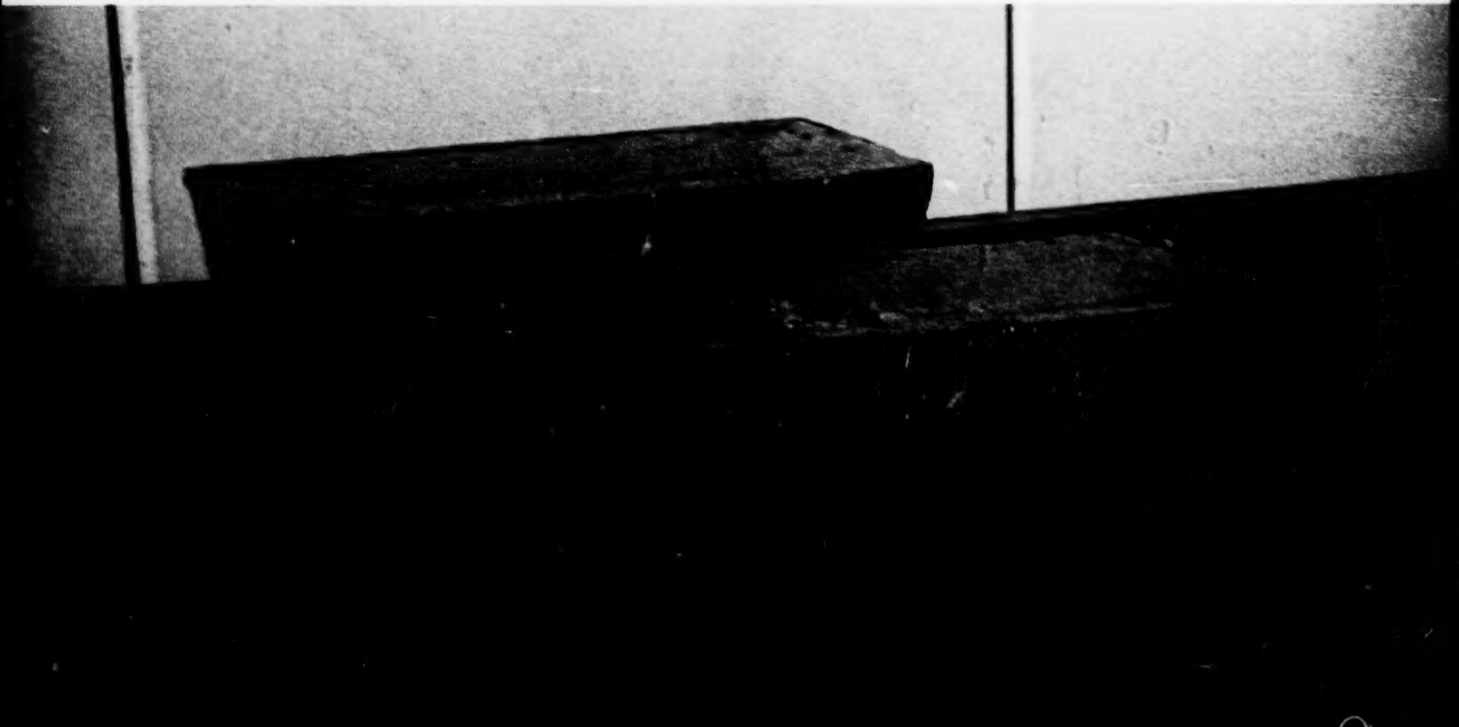
leakage of air creates a lubricating film between the load's pallet and the underlying surface. With friction thus minimized, it becomes possible to move loads at a one-to-one thousand force/weight ratio—meaning that a force of 150 pounds will move a load of 150,000 pounds.

In the mid-1960s, a group of General Motors engineers who had worked on the Marshall/General Motors air bearing system obtained a General Motors license for the technology and formed a company that subsequently became Rolair Systems. The company refined the technology and developed a broad line of air film transporters, turntables and air cushions for frictionless movement of practically any type of moderate to heavy load.

A challenging development in Rolair's early days was a system to move the world's largest jetliner, the Boeing 747, which has an empty weight of some 300,000 pounds. Rolair equipment has also been used by LTV Aerospace and Defense Company for lifting and assembling aircraft components, and by Rockwell International for movement of 150,000-pound titanium packs in aircraft construction operations.

Non-aerospace applications include a system capable of moving more than one million pounds of factory-built home modules from one assembly station to another; "floating" 60-ton Allis-Chalmers crawler tractors along the production line; and rearranging audience seating for TV and stage productions by sliding large sections of seats on an air film. A related assignment successfully handled by Rolair was development of a system for Hawaii's Aloha Stadium to shift four 7,000-seat sections and convert the stadium to optimum configuration for football, baseball, other sports and special events.

Since formation of the company, air flotation movement systems have been Rolair's speciality. The company has experienced substantial growth with increasing industrial acceptance of air film movement equipment and Rolair is now producing more than 100 standard systems in addition to customized designs. As part of this continued development, a new U.S. company has been formed: Hovair Systems Inc., Ventura, California, which combines Rolair's specialized experience with the broader industrial expertise of Hovair Systems Limited of England, Europe's foremost air film company.



Rolair equipment includes more than 100 types of air flotation systems for moving moderate to heavy loads. At left is a standard industrial-use transporter carrying a weight of 1,625 pounds; at right, six company employees add their weight to that of the metal blocks to demonstrate additional capacity.

Portable Computer

In November 1983, NASA flew a nine-day Space Shuttle mission that marked the initial use of the Spacelab orbital laboratory and several other "firsts." Little noticed in reports of that highly successful flight was another first: the space debut of a remarkable high performance navigation monitoring computer known to NASA as SPOC, for Shuttle Portable Onboard Computer. SPOC's debut was as successful as the rest of the mission and the small but highly capable computer is now used regularly on Shuttle flights. The photo at left shows a part of the Orbiter *Columbia's* flight deck with SPOC in use by astronaut John W. Young, commander of the Shuttle/Spacelab 1 mission.

SPOC was not a specially-developed system but an adaptation of a commercial computer called GRiD Compass, produced by GRiD Systems Corporation, Mountain View, California. Hardware had to be modified and new software developed to meet space requirements, which led to changes in commercial models that benefited the company's competitive position.

Since the Shuttle Orbiter's primary computers must handle a multitude of processing functions, NASA wanted a separate computer to provide reliable monitoring of the spacecraft's orbital path and a visual display of the Orbiter's position at any time. Since weight and space are vital considerations in Shuttle operations, the computer had to be small and light; nonetheless, it had to have graphic display capability, a large memory storage capacity, high processing speed and a degree of ruggedness sufficient to withstand launch vibration. After evaluating a number of small computers, NASA selected GRiD Compass.

The principal modification needed was a fan to cool the computer; GRiD computers are normally cooled by convection, or heat transfer by circulation, but that process does not work in weightless space. NASA also

wanted a larger electroluminescent screen and an improvement—for failsafe operation—to the lithium battery that powers the important internal clock. The power cord was modified to tap the Orbiter's power supply and Velcro strips were added to keep SPOC from floating. The fan was later incorporated into the larger screen models of the new Compass II line.

In Shuttle operations, SPOC automatically computes and displays the Orbiter's ground position, predicts the paths of the next two orbits, identifies locations where the Orbiter has line-of-sight communication with Earth stations, determines points for certain location-dependent Earth observations and continuously displays mission elapsed time. These demanding requirements necessitated a highly sophisticated operating and control system, one of the major considerations in NASA's selection of the GRiD Compass. Nonetheless, NASA and GRiD software engineers had to spend many hours writing, testing, and rewriting source code. This process, the company reports, ultimately benefited GRiD and its commercial clients, since it helped fine tune the GRiD Operating System and common code documentation.

Shown at left, the GRiD Compass computer weighs only 10 pounds, measures 15 inches in its longest dimension and is two inches thick when the screen is folded down; it slips easily into a standard briefcase. GRiD computers are manufactured in nine models using 17 integrated software packages. Widely used for office (above) and conference (upper right) work, the computers can also be used, with an optional battery pack for power, for field work (lower right); they have found special application among oil and natural gas companies for on-site drilling and production calculations, offering time and monetary savings over sending information gathered at a wellsite back to headquarters for computer analysis. For similar reasons, GRiD equipment is used by the U.S. Army as part of a field communications system. It is also used by AT&T Communications and Bell operating companies for on-site development of the detailed equipment layout plans for new or existing telephone buildings. Although the company is only five years old, it has already built a strong market base; GRiD Systems reports installations in more than 25 percent of the Fortune 1000 companies and in many government agencies. In addition, the GRiD computer's role in space flight is growing as NASA continues to expand the functions of SPOC.

Computer Code

In the course of developing the Space Shuttle, NASA developed a computer code for analyzing aerodynamic heating and heat transfer on the Shuttle. That computer code found secondary application in missile research conducted by The Marquardt Company, Van Nuys, California, which is engaged in research, development and manufacture of air-breathing propulsion systems, space rockets, turbo products and ordnance systems. The code was made available to Marquardt by NASA's Computer Software Management and Information Center (COSMIC)®. Located at the University of Georgia, COSMIC supplies to industrial and other customers computer software—originally developed for government projects—that has secondary utility.

Called MINIVER, the code was used by Marquardt engineers to analyze heat transfer on missile bodies designed for the U.S. Navy and the U.S. Air Force; the accompanying photo shows a missile body in a Marquardt test facility. The company selected the code because it offers capabilities for performing the requisite heat transfer analysis by four different methods; the four analyses can then be compared and checked to insure accuracy of the calculations. Marquardt reported savings of $15,000 and three man-months of computer analysis time that would have been required to develop a similar code had MINIVER not been available.

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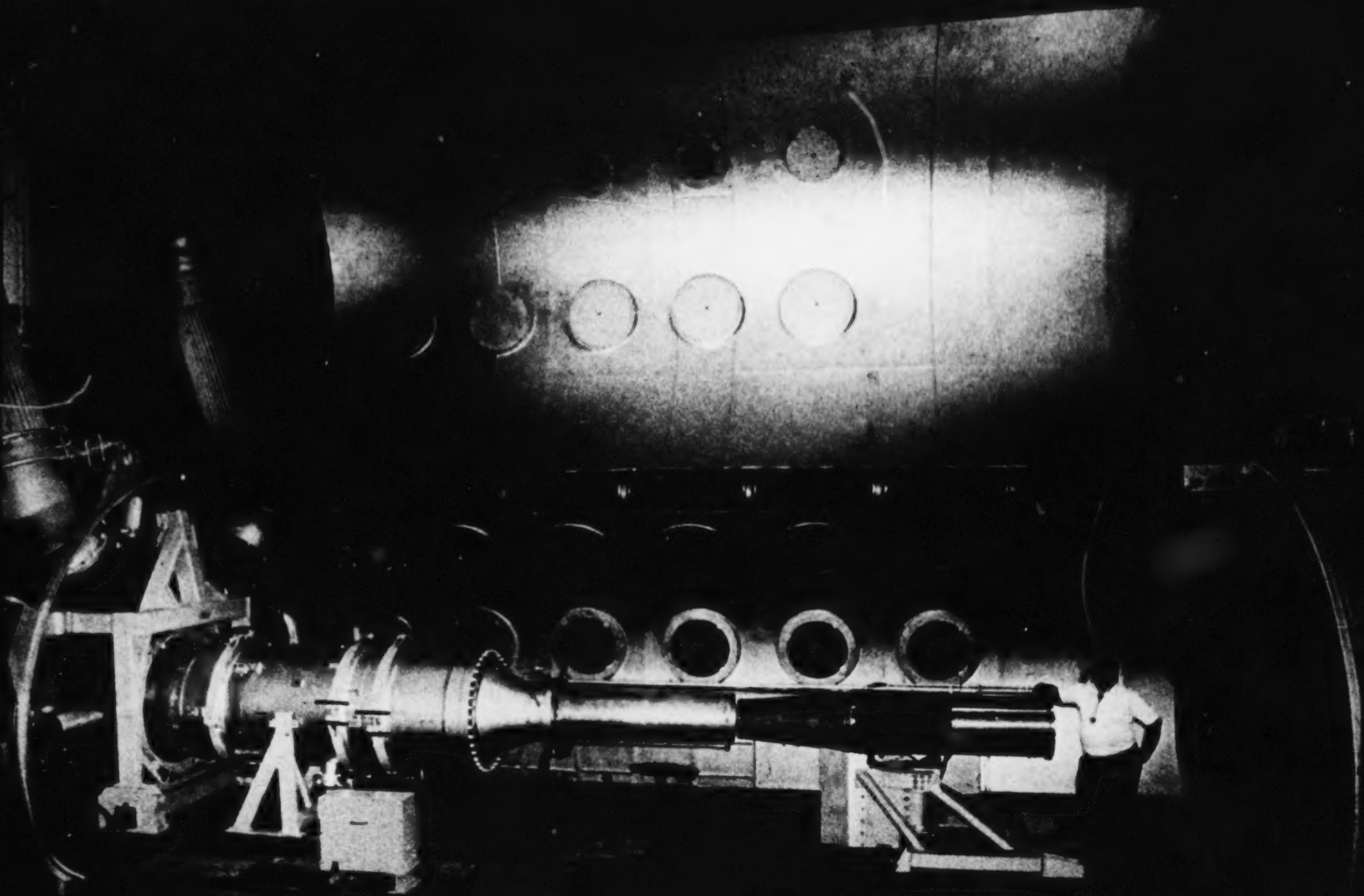
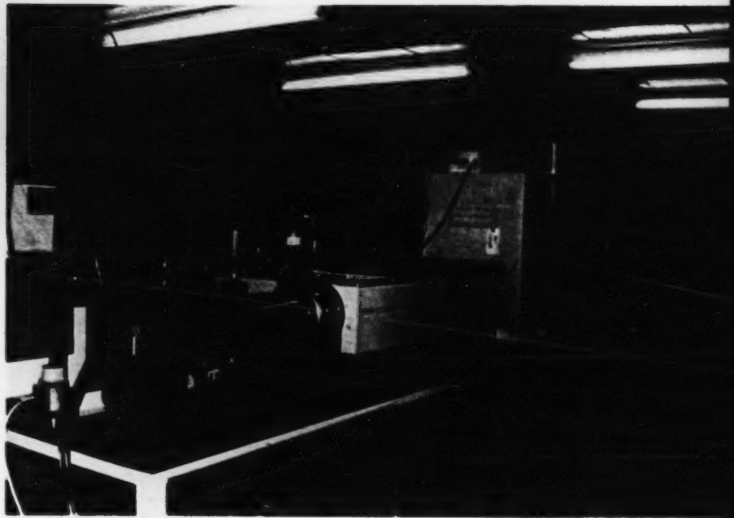


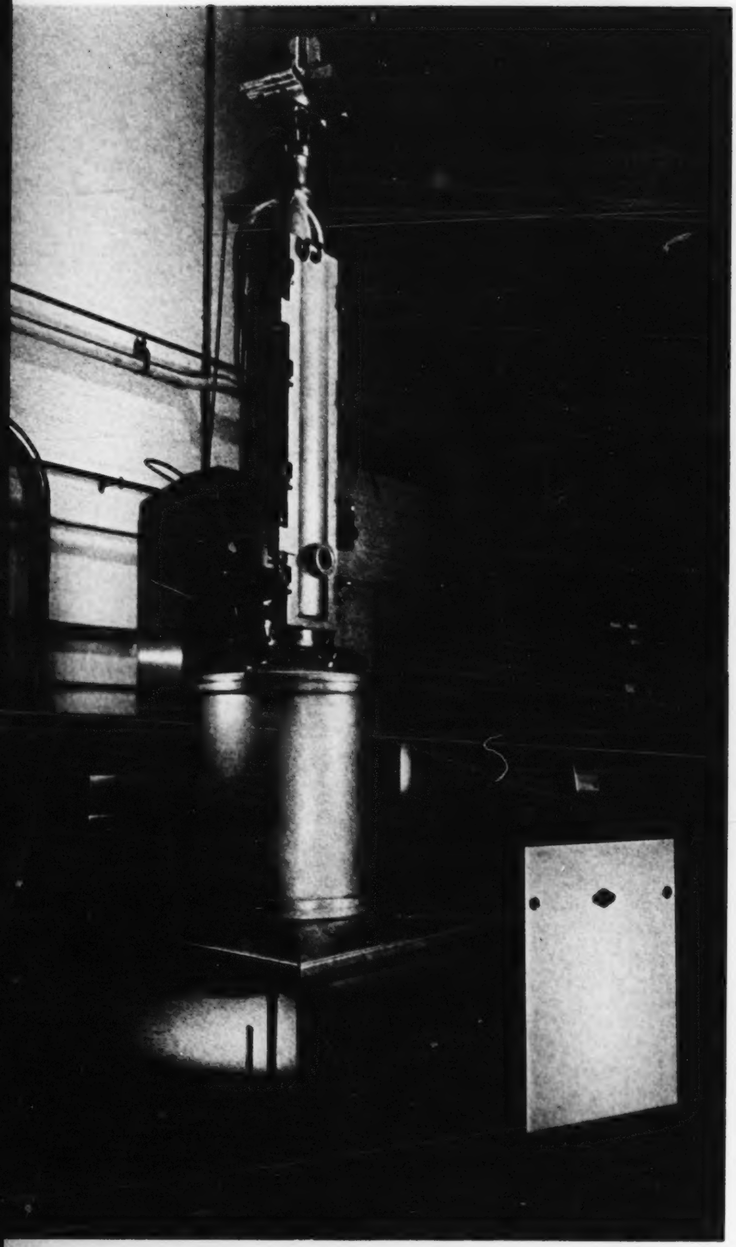
Laser Systems

Below, a technician is mounting a laser at Laser Analytics Division of Spectra-Physics, Bedford, Massachusetts. Laser Analytics produces high reliability laser systems for scientific and industrial use, including tunable diode lasers (TDLs) typically employed as radiation sources in high resolution infrared spectroscopy to determine or monitor the spectral characteristics of gaseous compounds. The lower photo exemplifies the use of a Laser Analytics product; it shows a TDL-based system for monitoring the core of a commercial gas-cooled nuclear power reactor at the Central Electricity Generating Board, Hartlepool, England. Other examples of TDL applications include a monitor for production of quartz halogen lamps at GTE Sylvania, Winchester, Kentucky and a system for monitoring chemical processes in manufacture of vulcanized silicone rubber sealant at General Electric Company's Silicone Products Division, Waterford, New York.

Laser Analytics credits the high reliability of its TDLs to a laser improvement program in the latter 1970s funded by Langley Research Center. Prior to that program, the company's TDLs were characterized by adequate performance but severe reliability problems. The Langley-sponsored program involved extensive experiments to determine the cause of TDL degradation. The research effort uncovered the fact that TDL degradation, which occurred during room temperature storage of the device, was associated with a phenomenon known as "intermetallic diffusion," a reaction between the lead-salt laser crystals and the metallic layers applied as contacts. This discovery led to an advanced metallization process that enabled laser shelf-life reliability values of more than five years. Laser Analytics says that the improvement in product reliability enhanced the company's competitive position and expanded sales of both scientific and industrial systems.



Crystal Furnace



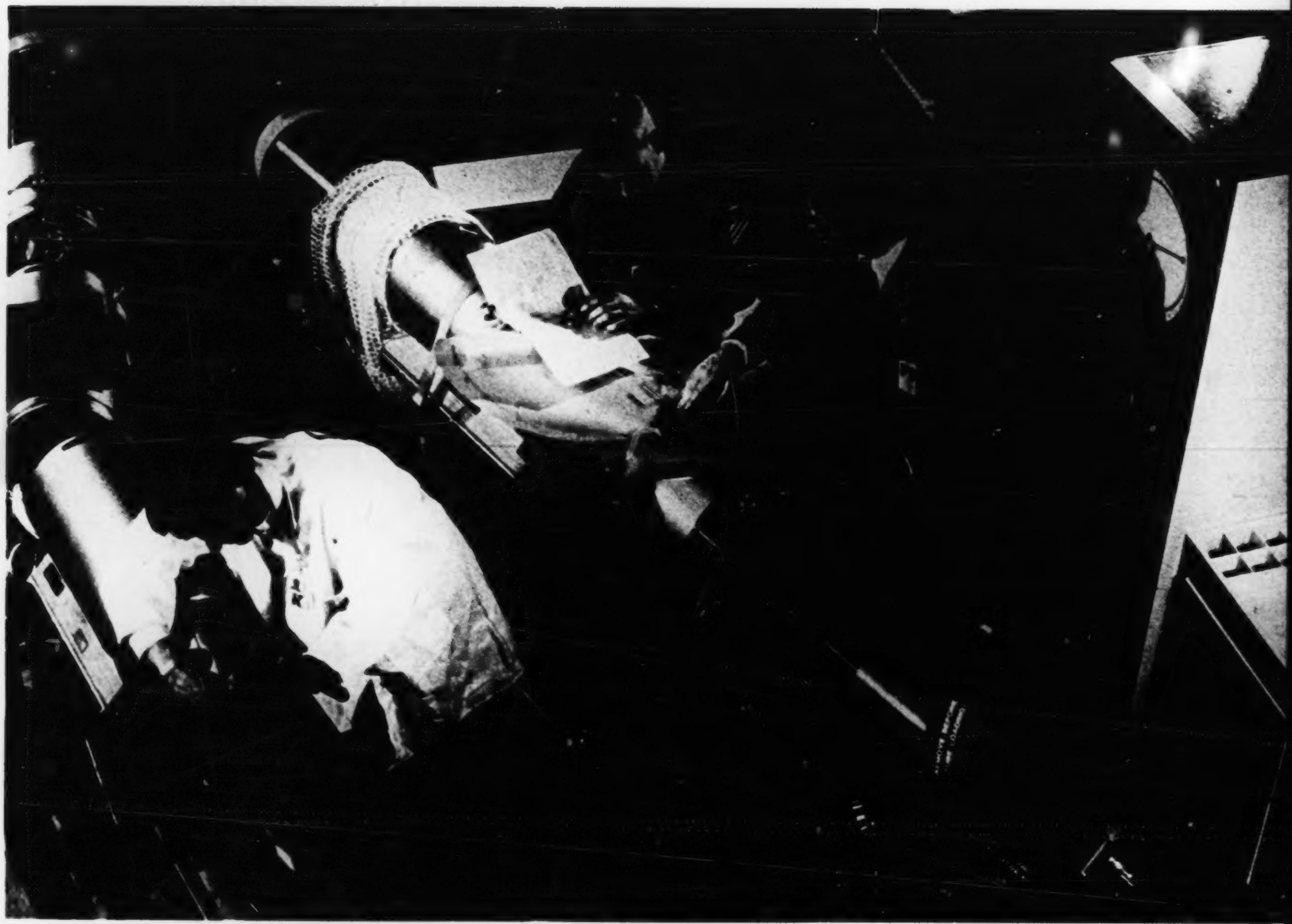
The system pictured is a Hamco CG6000 crystal growing furnace, manufactured by Kayex Corporation, a unit of General Signal, Rochester, New York and sold to industrial firms that grow crystals for use in semiconductors and solar cells. A key element in its operation is a "melt recharging" technique developed under contract to Jet Propulsion Laboratory (JPL).

In the latter 1970s, as part of the National Photovoltaic Program jointly sponsored by NASA and the Department of Energy, JPL was exploring ways to cut the cost of silicon solar cells, thin wafers produced by "growing" cylindrical silicon crystals in a furnace and slicing them. Normally, the crystal growing crucible had to be cooled after a run, then reheated and refilled with silicon. JPL accepted a Kayex proposal for an experimental program aimed at improving crucible productivity by serially growing several crystals from the same crucible through use of a melt recharger. This consisted of a hopper lowered into the hot zone of the crucible, making it possible to add raw silicon to an operating crucible. By eliminating the cooldown and heatup periods, the melt recharging method reduces the cost of crystals.

Kayex successfully accomplished a key development essential to melt recharding, an isolation valve that permitted lowering the hopper into the crucible without disturbing the inert gas atmosphere or lowering the melting temperature. Once the recharge method had been demonstrated to be effective, Kayex advanced the technology to allow growth of larger crystals and increase crucible capacity to 60 kilograms, from about 20 kilograms in an existing CG2000 Kayex system. This was done by redesigning the CG2000 and scaling up its parts. The Kayex/JPL prototype thus developed performed well over a monitoring period of several months.

Kayex engineers and designers then used the operational results and measurements from the JPL grower as the basis for designing the advanced CG6000 which, in production use, proved to outperform the earlier CG2000 by as much as 50 percent. The CG6000 has become the company's major product.

Absorbent Material



The accompanying photo shows a pair of Mark 50 "smart" torpedos being readied for delivery to the U.S. Navy at a Honeywell Inc. facility in Keyport, Washington. NASA technical information helped Honeywell engineers solve a problem occasioned by a Navy requirement for operating the Mark 50 at considerable depth.

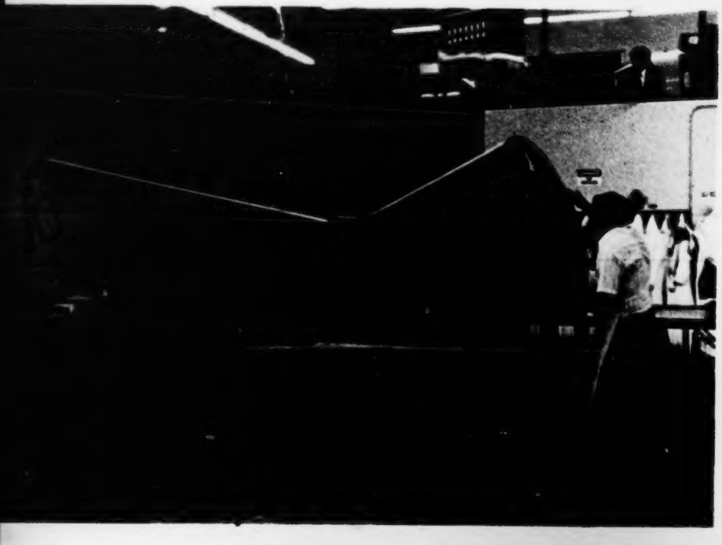
Test runs disclosed that, as operating depth increased, ocean pressure tended to force sea water through the hull assembly joints, degrading torpedo reliability by possible short-circuiting of the electronic controls. Thus leak depth—rather than the depth at which pressure would crush the hull—became a limiting factor in the performance of the torpedo.

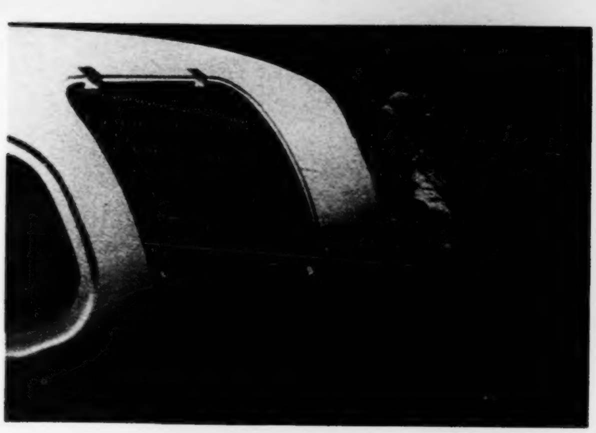
Honeywell sought a way of correcting the problem without expensive and time-consuming redesign of the system. A company engineer recalled an article published in NASA's *Tech Briefs*, a publication that details new technology developed in the course of NASA programs; the article described a superabsorbent fabric developed by Johnson Space Center (JSC) for capturing human wastes in manned spacecraft. Honeywell contacted JSC, obtained additional details and was referred to an acceptable manufacturer of the absorbent material.

Honeywell then procured the material and fabricated it into special containment devices now used on the Torpedo Mark 50. The absorbent fabric can sequester up to 400 times its own weight in water; therefore, a relatively small amount of it is sufficient to protect the Mark 50 from deepwater hull seepages. Instead of the great expense the company would have incurred in redesigning the torpedo or its hull joints, Honeywell's cost of correcting the problem was on the order of one man-week.

Composite Materials

At right is the Avtek 400 experimental business airplane, a twin turboprop that was introduced to flight test last September. Developed by Avtek Corporation, Camarillo, California, the airplane is distinguished by the fact that its airframe is made entirely of composite materials, which generally are lighter but stronger than the metals they replace.





A number of military and commercial aircraft already in operational service have components made of composites, but the Avtek 400 is among the first all-composite aircraft. Increasing use of composites in airframes is a trend of the future because of the singular advantages they offer in comparison with metal structures: improved performance, dramatically lower weight and, in some cases, reduced cost.

The principal materials used in the Avtek 400 are Kevlar® aramid fiber and Nomex® aramid, both developed by The Du Pont Company, Wilmington, Delaware, a pioneer in development and manufacture of materials for composites. Kevlar is a fiber that, pound for pound, is five times as strong as steel. Nomex is Du Pont's trade name for a family of high strength, high temperature resistant aramid sheet structures, staple fibers and filament yarns. More than 70 percent of the Avtek 400 is made of honeycomb of Nomex sandwiched between skins of Kevlar fiber. Honeycomb is a series of cells grouped together to form a panel similar in appearance to a cross-sectional slice of a beehive. It is 90 to 99 percent open space, hence extremely light; when the core of Nomex is bonded between two surfaces, the resulting sandwich structure has exceptionally high strength-to-weight and rigidity-to-weight ratios.

Use of Kevlar and Nomex in the Avtek 400 combine to give the airplane a light, tough structure that has a maximum weight of only 5,500 pounds, about half the weight of a metal airplane of comparable size and performance. Composites can be molded into many aerodynamic shapes, eliminating most of the rivets and fasteners required in metal construction. The

Avtek 400 is made of 48 molds. The middle photo, opposite page, shows the aft section and vertical stabilizer; at lower left is the forward section.

NASA's Langley Research Center is among the world's leading organizations for research on composite structures. Langley has conducted extensive investigation and test on applying composites to space vehicles, commercial aircraft, military aircraft and helicopters; such work included application testing components of Kevlar that assisted Du Pont in the company's own advancement of its product. Specifically, Langley conducted research in support of Space Shuttle use of pressure bottles filament-wound with Kevlar, a weight saving measure. That development led to use of similar bottles to activate escape slides in the Boeing 747 and 757 jetliners at a saving of 20 pounds per bottle. A Langley/Lockheed Corporation experimental program involving use of composites—including Kevlar—on the L-1011 transport fostered adoption of fiber reinforced parts on such new aircraft as the Boeing 757 and 767, both of which employ significant amounts of hybrid structure composed of Kevlar, carbon and epoxy.

The growing use of composites in aerospace applications is exemplified by Du Pont statistics. In 1983, Du Pont shipments of Kevlar and Nomex to the aerospace industry were used to produce composite parts worth more than $500 million; the company estimates that by 1988 it will be shipping three times as much for aerospace applications alone.

Use of composites is rapidly spreading to other markets—boats, for instance. A large percentage of small pleasure and commercial boats already incorporate composites and the trend is being extended to larger vessels to take advantage of the weight reduction and performance gains composites offer. Shown below is the 80-foot yacht *Kialoa,* whose hull is reinforced with Kevlar fiber; the fiber's toughness increases the hull's resistance to damage and Kevlar's lightness provided new design latitude in distributing weight for maximum sailing efficiency. Du Pont composites are also finding increasing use in such other applications as transportable military shelters, components of automotive vehicles, protective apparel for people in hazardous professions, marine-use ropes and cables, and a broad variety of industrial uses.

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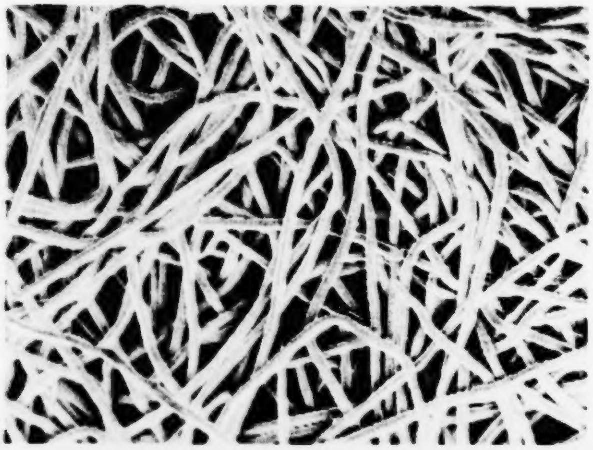
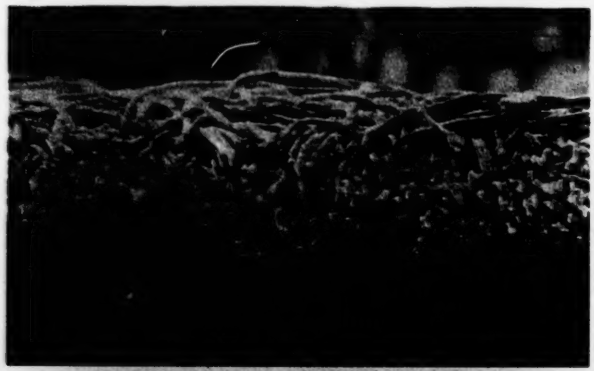
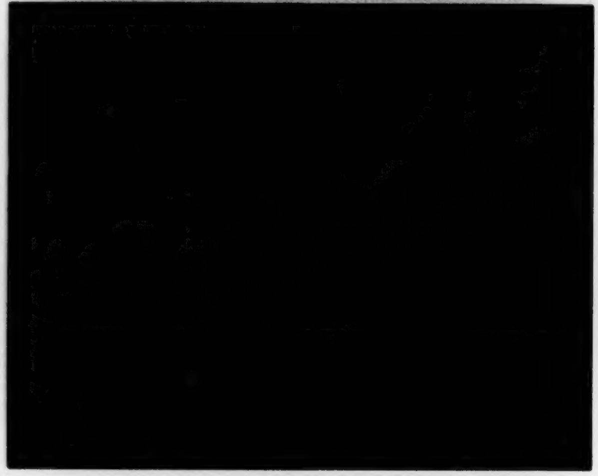
Metallic Filters







HR Textron, a subsidiary of Textron, Inc. located in Pacoima, California is a major producer of industrial filters through its Filter Products Division. The division supplies equipment for such applications as filtering polyesters and other plastics, removing solids from hydrocarbon streams, water filtering, oil well filtration, removing contaminants from crude feed stocks and filtration of liquid and gas streams in coal liquefaction/gasification processing.

The heart of each HR system is 421 Filter Media, composed of a matrix of ultrafine steel fibers metallurgically bonded and compressed so that the resultant pore structure is locked in place; thus each pore is virtually unchangeable in size for the life of the filter. The upper picture is a photomicrograph top view of 421 filter material; the middle photo is an edge view. The matrix is reinforced with woven wire mesh. To maximize surface area, the medium is pleated (bottom photo) and wrapped onto a stainless steel core; the division also offers unpleated configurations. HR Textron guarantees removal of contaminants down to one micron (millionth of a meter) and states that, for a given filter size and rating, the 421 capillary network holds four times or more contaminants than an ordinary metal filter. The Filter Products Division produces 421 elements in a low pressure series, for applications up to 150 pounds per square inch, and a high pressure series that provides effective filtration up to 6,000 pounds per square inch.

HR's patented 421 Filter Media, described by the company as a major advance in filtration technology, originated in a mid-1960s NASA-sponsored study concerning types of filter media useful in space systems. Conducted for Marshall Space Flight Center by Arthur D. Little Company, the study concluded that spun metal fiber filters offered particular promise for space applications and recommended further research in that area. NASA distributed the study to the filter industry to encourage such effort and HR Textron responded, using the study as a departure point for its own, company-funded development of 421 Filter Media. HR subsequently provided 421 to NASA for use in the Apollo and Saturn launch vehicle programs, then successfully branched out into the non-aerospace market. The company's filter units are used by major companies—such as Du Pont, Eastman Kodak, Dow Chemical and Monsanto—in chemical processing operations; other applications include petrochemical products, pharmaceuticals, industrial hydraulics, pollution control and manufacture of man-made fibers, films and resins.

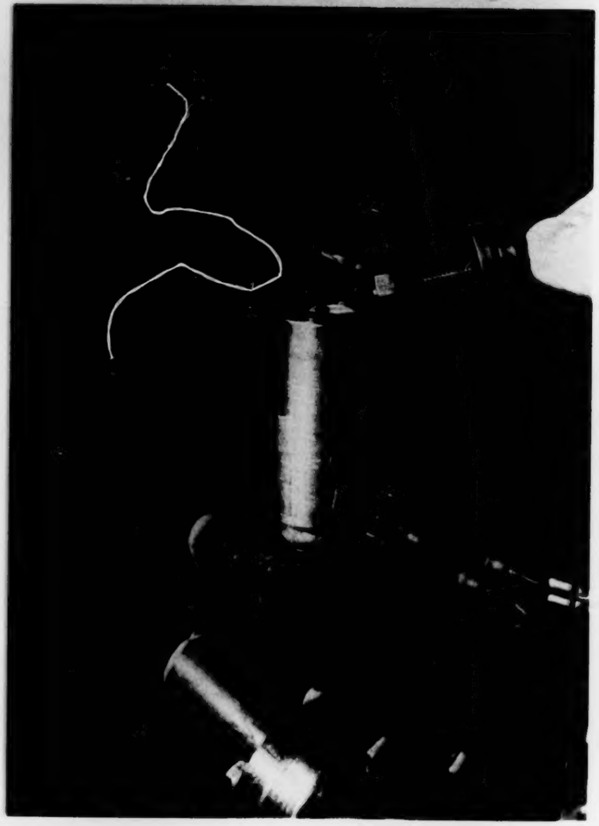
Pressure Relief Valve

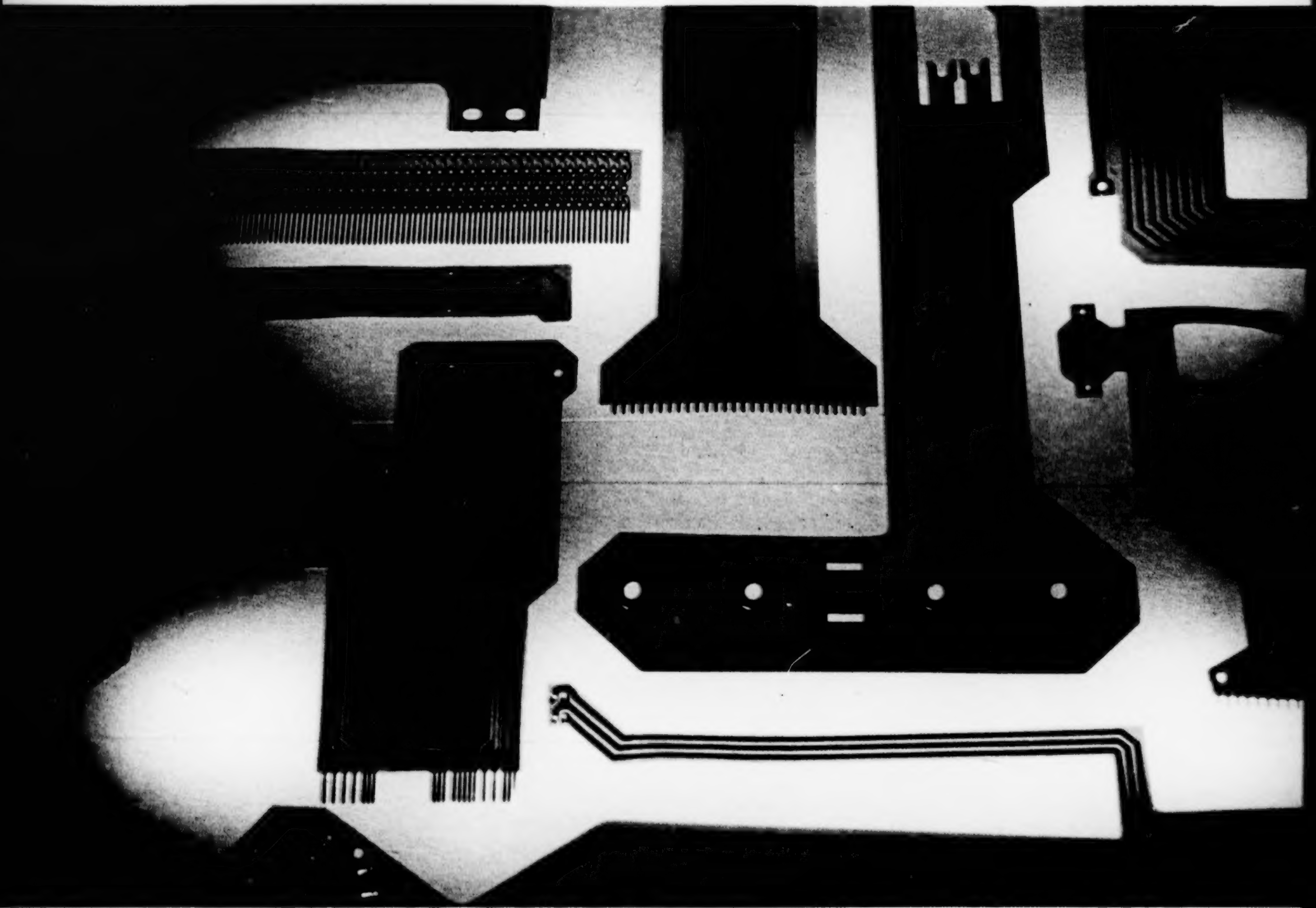
Deposition Technology, Inc. (DTI), San Diego, California is an industry leader in the technique of "sputtering," the process of applying filmlike metal coatings onto a substrate, or surface, by bombarding the coating material with electrocharged ions; this causes the material to disintegrate and relocate on the substrate an atom layer at a time. The process allows deposition of a great variety of coating materials—metals, dielectrics and semiconductor materials, for example—on many different types of surfaces.

Extremely thin or thick films can be deposited in uniform layers and it is possible to deposit composite layers of different materials, which opens up a new range of applications. DTI's principal use of sputtering is production of window films for sunlight-blocking glare reduction and evergy savings. The company also provides sputtered coatings for such other applications as packaging materials, electronic circuit boards, solar energy systems, medical uses and dielectric imaging.

At DTI, metal and other coatings are deposited on the substrate in a sputtering chamber shown above. At top right, the finished product of the wide web sputtering system emerges as a 62-inch roll of coated material.

NASA technical information contained in the technology transfer publication *Tech Briefs* provided a productivity-improving benefit to DTI: a special type of valve—originally developed by Lewis Research Center—that relieves pressure beyond a specified limit by allowing gas to escape from a pressurized system. Such valves are installed on two vacuum chambers that are part of DTI's sputtering system. It is common practice to vent a vacuum chamber to a dry, inert gas following a chamber run. Because the gas is under pressure, it is necessary to protect delicate vacuum gauges and other components from overpressure. DTI's use of the NASA-developed valve (above) not only protects the equipment but also frees the operator from monitoring the chamber venting. Fabrication and installation of the valves involved only nominal cost. DTI reports that the valves save an estimated 40 man-hours yearly in addition to avoidance of the substantial downtime and expense that might have resulted from overpressure of sensitive components.





Sculptured Circuits

At left is a selection of sculptured flexible etched circuits for electronic systems; they are designed and manufactured by Advanced Circuit Technology (ACT), Nashua, New Hampshire. Marketed as Sculptured® Interconnects, the circuits were developed as an advancement over conventional etched circuits that lack the ability to terminate, hence require attached pins or connectors. Such added hardware is eliminated in ACT's sculptured circuits, which are made with built-in terminals. Produced by a patented manufacturing process, the company's sculptured circuits are offered in standard configurations or in custom designs to fit specific applications.

The photos illustrate some steps in ACT circuit design and manufacturing. At lower left, an engineer is designing a circuit with the aid of computer graphics; the adjacent photo shows a finished copper circuit plate; at upper right, sculptured circuits are being assembled in the company's manufacturing room; a closeup of a circuit assembly table is shown at lower right.

ACT is an example of the growing number of industrial firms taking advantage of a productivity improvement service offered by NASA through a network of user assistance centers that provide information retrieval services and technical help. The center in this case is the New England Research Applications Center (NERAC), Storrs, Connecticut. NERAC conducts computerized literature searches to find and apply technical information pertinent to a client's needs.

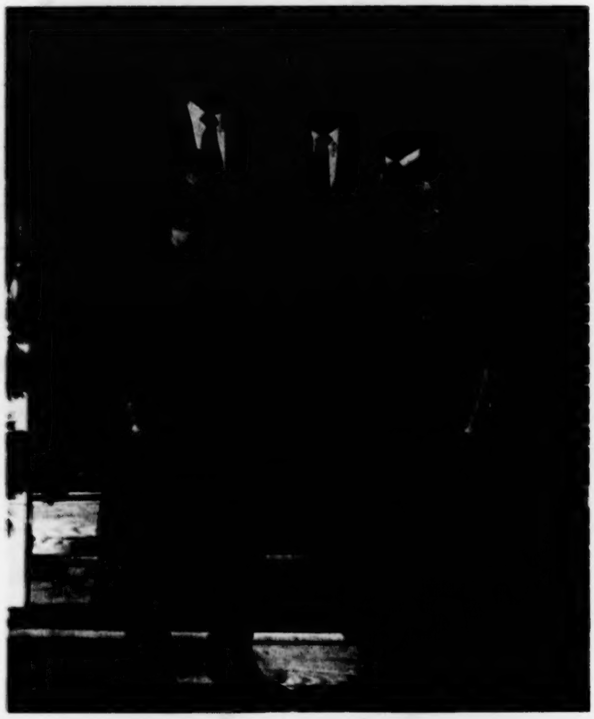
ACT's product research and development group regularly employs NERAC's search service to stay abreast of new developments in interconnection technology and, in particular, to find new opportunities for applying its sculptured circuit process. NERAC provides information in such areas of company interest as materials and processes used in printed circuit fabrication, new interconnection products and latest advances in manufacturing technology.

Search efforts divide into two classes: currency—aimed at company awareness of broad trends in electronics development and manufacture—and product intelligence, research of a more specific nature directly applicable to ACT development programs. NERAC furnishes abstract listings to ACT personnel, who periodically follow up with requests for full length reprints of documents that seem to warrant detailed study. ACT has several new products in development and the company reports that each of them has benefited from NERAC's computerized technology search.

®Sculptured is a registered trademark of Advanced Circuit Technology Inc.

Error-free Software

In the 1960s, during the development phase of NASA's Apollo lunar landing program, Johnson Space Center awarded a contract to The Charles Stark Draper Laboratory, Inc., Cambridge, Massachusetts—then affiliated with Massachusetts Institute of Technology—for onboard guidance, navigation and control of the Apollo spacecraft. Two women played important roles in that highly successful effort: mathematician Margaret H. Hamilton, who directed development of Apollo onboard computer software,



and physicist Saydean Zeldin, section head for the guidance portion of that development. Their Apollo experience included extensive analysis of computer errors, which led to their later formulation of a mathematical theory for development of "higher order" software designed to catch computer mistakes early. In 1976, they formed Higher Order Software, Inc. (HOS) in Cambridge to develop and market an engineering tool that corrects computer errors at the entry level, a system termed by experts a major advance in computer technology. Hamilton (left in the above photo) and Zeldin are pictured with executives of HOS.

Hamilton and Zeldin began their error investigations after the first lunar landing in 1969. Over a period of years, they studied mistakes and how they might have been prevented, which resulted in an organized system of error analysis and correction. They sought to define a system free of ambiguities or "interface errors," meaning software that is logically incomplete, redundant or inconsistent. After leaving Draper to form HOS, they devoted five years to a program of research and development. From the NASA analysis of error classification and correction came the mathematical theory for a way to design software so that it is logically error-free. HOS developed a software engineering tool that was first tested in a 1981 Department of Defense project; it was found to increase productivity by 600 percent and to reduce costs by 83 percent on that project. In 1983, HOS began marketing an error correction computer program called USE.IT.

USE.IT employs the computer to automate the systems development process, eliminating human logic and implementation errors; first it assists the systems designer in defining objectives, then it automatically produces an error-free program code that eliminates data entry mistakes—thereby generating considerable savings in time and money. A major advantage of the system is its language—called AXES—which resembles normal language so that a user can write functions in English and the system will convert the code to conventional computer languages. Because debugging and code generation are automatic, a person with no programming experience could write software with USE.IT.

USE.IT has found wide acceptance in a short time. HOS clients include many of the nation's largest companies, who employ it in such applications as manufacturing, banking and insurance. The software tool is mounted on Digital Equipment Corporation's VAX computers and HOS is now designing a system for mainframe computers, a broader market. Last year, the NASA-originated software came full cycle when The Singer Company's Link Division became a USE.IT client; Link designs and builds flight simulation equipment for Space Shuttle crew training.

Technology Utilization

A description of the mechanisms employed to encourage and facilitate practical application of new technologies developed in the course of NASA activities and to stimulate industry interest and investment in commercial use of space.

Putting Technology to Work

In a comprehensive nationwide effort, NASA seeks to increase public and private sector benefits by broadening and accelerating the secondary application of aerospace technology

The wealth of aerospace technology generated in the course of NASA programs is an important national asset in that it offers potential for secondary applications—new products and processes that collectively represent a valuable contribution to the U.S. economy. But such technology transfers do not materialize automatically; translation of the potential into reality requires an organized effort to put the technology to work in new applications and reap thereby a dividend on the national investment in aerospace research.

NASA's instrument for accomplishing that objective is the Technology Utilization Program, which employs several mechanisms intended to broaden and accelerate the transfer of aerospace technology to other sectors of the economy. An example is the work of the Technology Utilization Officers (TUOs), a group of technology transfer experts—located at each of NASA's nine field centers—who serve as regional technology utilization program managers.

The TUO's basic responsibility is to maintain continuing awareness of research and development programs conducted by his center that have significant potential for generating transferable technology. He assures that the center's professional people identify, document and report new technology developed in the center laboratories and, together with other center personnel, he monitors the center's R&D contracts to see that contractors similarly document and report new technology, as is required by law. This technology, whether developed in-house or by contractors, becomes part of the NASA bank of technical knowledge that is available for secondary use.

The TUO's next job is "getting the word out"—advising potential users of the technology's availability. To do so, he evaluates and processes selected new technology reports for announcement in NASA publications and other dissemination media. Prospective users are informed that more detailed information is available in the form of a Technical Support Package, which the TUO prepares and distributes in response to inquiries.

The TUO also acts as a point of liaison between industry representatives and personnel of his center, and between center personnel and others involved in applications engineering projects, efforts to solve public sector problems through the application of pertinent aerospace technology. On such projects, the TUO prepares and coordinates applications engineering proposals for joint funding and participation by other federal agencies and industrial firms.

NASA conducts—independently or in cooperation with other organizations—a series of conferences, seminars and workshops designed to encourage broader private sector participation in the technology transfer process and to make private companies aware of the NASA technologies that hold promise for commercialization. The TUO plays a prominent part in this aspect of the program. He arranges and coordinates his center's activities relative to the meetings and when—as frequently happens—industry participants seek to follow up with visits to the center, he serves as the contact point.

In sum, the TUO stays abreast of NASA technical advances at his center, identifies new technology that might be productively reapplied, promotes interest among prospective users and provides assistance to expedite the transfer process.

Support for the TUOs—and for all other groups within the NASA technology utilization network—is provided by the technology utilization office at the NASA Scientific and Technical Information Facility. The facility's Technical Services Group handles centralized maintenance and reproduction of all Technical Support Packages (TSPs) maintaining more than 6,000 master copies of TSPs, which are reproduced on request. Additionally, it responds to more than 80,000 inquiries a year, conducting search and retrieval services to identify relevant information. Responses include enclosures such as technology utilization documents, reference data and bibliographic data, or referrals to Industrial Application Centers on highly technical questions requiring in-depth search and retrieval. The group is also responsible for distribution of technology utilization publications.

Technology Utilization Officers at each of NASA's field centers serve as regional technology utilization program managers. The center pictured is Ames Research Center.

NASA's Technology Utilization Program is managed by the Technology Utilization Division, an element of the Office of Commercial Programs. Headquartered in Washington, D.C., the division coordinates the activities of the TUOs and other technology transfer specialists located throughout the U.S. In addition to the work of the TUOs, other mechanisms employed by the division include a network of user assistance centers that provide information retrieval services and technical help to government and industry clients; the earlier mentioned applications engineering projects; a quarterly publication that informs potential users of new technologies available for transfer; and a software center that provides, to industry and government organizations, computer programs adaptable to secondary use. These mechanisms are amplified on the following pages, along with a summary of NASA's activities in the related area of commercial development of space.

The Technology Utilization Office staff at Marshall Space Flight Center discuss the Power Factor Controller (foreground), a Marshall invention that has become one of the most widely used aerospace technology transfers.

NASA conducts a series of conferences, seminars and workshops intended to promote broader private sector participation in technology transfer.

Commercial Development of Space

The key to exploiting space opportunities for Earth benefit is expanded private sector investment and involvement in civil space activities. NASA's role is to encourage and facilitate the commercial use of space and to provide assistance to companies interested in pursuing commercial space ventures, such as those exemplified in the accompanying photos. Photo at left shows a group of crystals grown in a 1984 Shuttle-based experiment conducted by 3M Company, which hopes that crystals like these—larger and with fewer defects than Earth-grown crystals—will find application in future 3M products. In photo on the opposite page McDonnell Douglas Astronautics engineer Charles J. Walker is checking the company's EOS system for separating biological materials in the weightless environment of space; flown on several Shuttle missions, the EOS experiments are expected to lead to commercial production of advanced pharmaceuticals.

The focal point of NASA's commercial space development effort is the Office of Commercial Programs, located in NASA's Washington, D.C. headquarters. The agency's program offices and field centers also play important parts in supporting NASA's commercial space initiatives and assisting private companies. The activities of these offices are governed by a NASA Commercial Use of Space Policy announced in 1984. The policy statement lists five guiding principles:

- The government should establish new links with the private sector, broadening its traditional association with the aerospace industry and the science community to include relationships with non-aerospace firms, academia and the financial community.
- Regardless of the government's view of a project's feasibility, it should not impede private efforts to undertake space ventures.
- If the private sector can operate a space venture more efficiently than the government, such privatization should be encouraged.
- The government should invest in high-leverage research and space facilities which encourage private investment. However, the government should not expend tax dollars for endeavors the private sector is willing to fund.
- When a major government contribution to a commercial endeavor is requested, two requirements must be met: the private sector must have significant capital at risk and there must be significant potential benefit to the nation.

To implement the policy, NASA is actively supporting commercial development of space commercialization in these areas, listed in order of importance:

- New commercial high technology ventures
- New commercial application of existing space technology
- Transfer of existing aeronautics and space programs to the private sector

The policy lists a series of initiatives intended to reduce the risks of doing business in space and thereby encourage greater private investment.

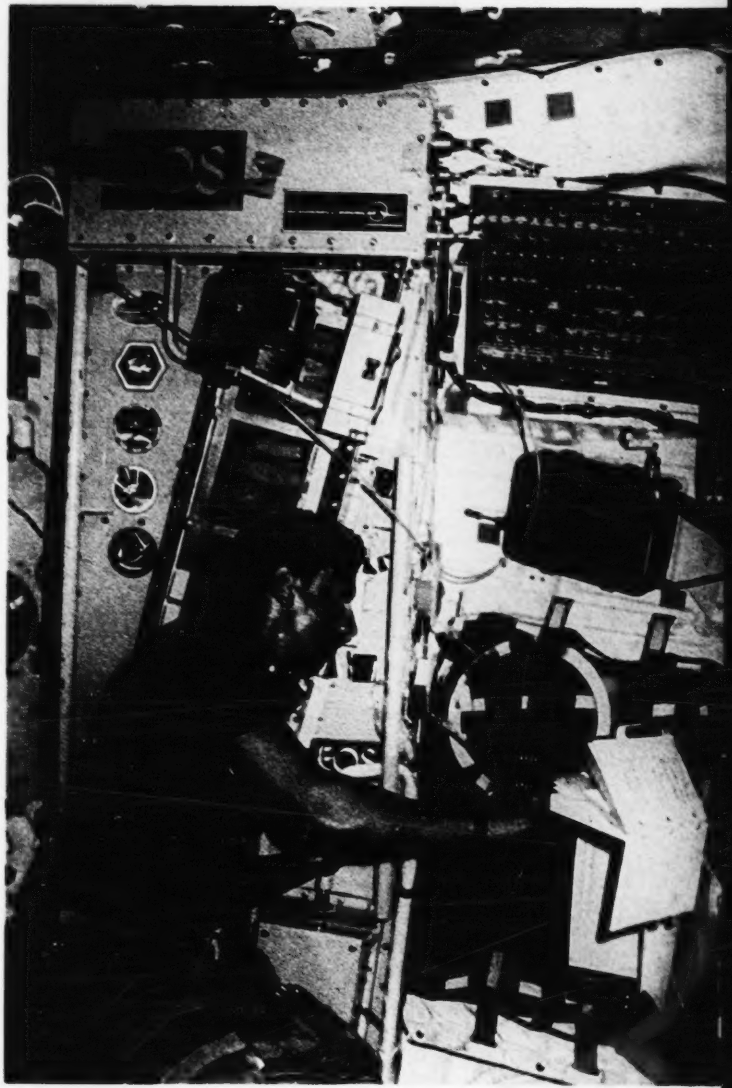
To reduce *technical* risks, NASA will support research aimed at commercial applications, ease industry's access to NASA facilities, establish flight opportunities for commercial payloads, expand availability of technological information of commercial interest, and support development of new facilities for commercial uses of space.

To reduce *financial* risks, NASA will continue to offer reduced-rate space transportation for high technology endeavors and assist in integrating commercial equipment with the Shuttle.

To reduce *institutional* risks, NASA will speed integration of commercial payloads with the Space Shuttle Orbiter; shorten the time for evaluation of joint NASA/private sector proposals; establish procedures for encouraging development of space hardware and services with private capital instead of government funding; and create new institutional approaches for strengthening NASA's support of private investment in space.

A major part of NASA's effort is the outreach program, intended to explain commercial use of space to interested businesses and public sector organizations; to expand NASA/industry/university relationships; and to solicit the counsel, talent, insight and experience of the aerospace, non-aerospace, financial and insurance communities.

Among outreach initiatives are NASA-sponsored invitational workshops designed to bring together NASA and industry researchers for discussions in specific research areas related to programs with commercial potential; seminars for investment banking and insurance interests to provide information that will enable the financial community to make informed judgments on investment opportunities and risks; and seminars for entrepreneurs on the commercial potential of ongoing NASA research and development programs.



Publications

An essential measure in promoting greater use of NASA technology is letting potential users know what NASA-developed information and technologies are available for transfer. This is accomplished primarily through the publication *NASA Tech Briefs*.

The National Aeronautics and Space Act requires that NASA contractors furnish written reports containing technical information about inventions, improvements or innovations developed in the course of work for NASA. Those reports provide the input for *Tech Briefs*. Issued quarterly, the publication is a current awareness medium and a problem solving tool for its many government and industry readers.

First published as single sheet briefs in 1962, *Tech Briefs* was converted to a NASA-published magazine format in 1976. The Spring 1985 issue marked a new milestone in that publishing responsibility, including sale of advertising, was turned over to a commercial firm in a joint venture between NASA and Associated Business Publications (ABP) of New York City. Thus, *Tech Briefs* became the first government publication in history to accept paid advertisements, an arrangement that relieves the government of publication costs and permits an increase in circulation; budgetary constraints had necessitated a circulation ceiling of 75,000 per issue, but the joint venture has removed the ceiling.

NASA continues to supply the editorial matter for *Tech Briefs* and the basic format remains essentially unchanged. Each issue contains information on approximately 100 newly-developed processes, advances in basic and applied research, improvements in shop and laboratory techniques, new sources of technical data and computer programs. Interested firms can follow up by requesting a Technical Support Package, which provides more detailed information on a particular product or process described in the publication. Innovations reported in *Tech Briefs* annually generate more than 100,000 requests for additional information, concrete evidence that the publication is playing an important part in inspiring broader secondary use of NASA technology.

Tech Briefs is available to scientists, engineers, business executives and other qualified technology transfer agents in industry or in state and local governments. The publication may be obtained by contacting the Director, Technology Utilization Division, NASA Scientific and Technical Information Facility, Post Office Box 8757, Baltimore/Washington International Airport, Maryland 21240.

A related publication deals with NASA patented inventions available for licensing, which number almost 4,000. NASA grants exclusive licenses to encourage early commercial development of aerospace technology, particularly in those cases where considerable private investment is required to bring the invention to the marketplace. Non-exclusive licenses are also granted, in order to promote competition and bring about wider use of NASA inventions. A summary of all available inventions, updated semi-annually, is contained in the NASA Patent Abstracts Bibliography, which can be purchased from the National Technical Information Service, Springfield, Virginia 22161.

Applications Centers

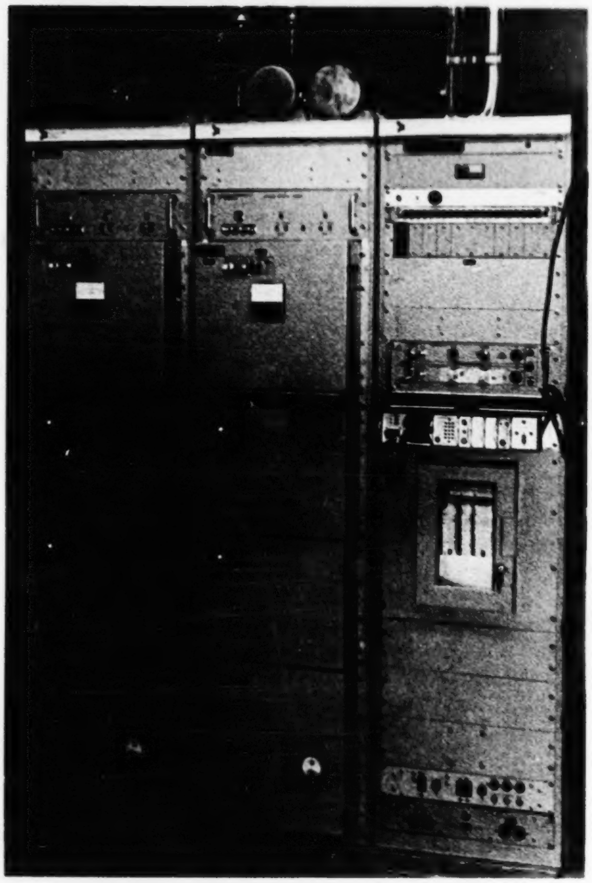
To promote technology utilization, NASA operates a number of user assistance centers whose job is to provide information retrieval services and technical help to industrial and government clients. There are nine Industrial Application Centers (IACs) affiliated with universities across the country. The centers are backed by off-site representatives in many major cities and by technology coordinators at NASA field centers; the latter seek to match NASA expertise and ongoing research and engineering in areas of particular interest to clients.

The network's principal resource is a vast storehouse of accumulated technical knowledge, computerized for ready retrieval. Through the applications centers, clients have access to more than 10 million documents. More than two million of these documents are contained in the NASA data bank, which includes reports covering every field of aerospace-related activity plus the continually updated, selected contents of some 15,000 scientific and technical journals.

How this technology is put to work is exemplified by the work of one of the centers—the Southern Technology Applications Center, Gainesville, Florida—in providing assistance to a company producing troposcatter terminals. The troposcatter mode of radio transmission permits single hop, high quality voice or digital communications up to 750 kilometers. Since transmission is accomplished by bouncing signals off the troposphere, signal degradations known as fading and multipath are encountered. Troposcatter terminals correct these degradations to assure message integrity. Each terminal consists of transmitters ranging in output power from 100 watts to 100 kilowatts. Transmit power and antenna size are a function of distance and the quantity of information transmitted.

REL, Inc., Boynton Beach, Florida is a pioneering design organization in troposcatter communications that has designed and built a number of terminals for the military services, such as the one pictured. Although REL maintains its own library of technical information, the company felt it prudent to employ STAC's service to provide all available information on the latest design techniques for troposcatter systems.

STAC conducted a computer search of four data bases, including NASA's, and provided information that enabled REL engineers to evaluate their own technology in light of the latest innovations in the field. Based on some unique references STAC turned up, REL ordered several documents that were relevant. Information contained in those documents was subsequently used by REL to modify its design concepts to produce an improved troposcatter terminal. The company's director of research and development called STAC's effort "one of the most thorough reviews conducted in our field."



Intended to prevent wasteful duplication of research already accomplished, the IACs endeavor to broaden and expedite technology transfer by helping industry to find and apply information pertinent to a company's products or problems. By taking advantage of IAC services, businesses can save time and money and the nation benefits through increased industrial efficiency.

Staffed by scientists, engineers and computer retrieval specialists, the IACs provide three basic types of services. To an industrial firm contemplating a new research and development program or seeking to solve a problem, they offer "retrospective searches"; they probe appropriate data banks for relevant literature and provide abstracts or full-text reports on subjects applicable to the company's needs. IAC's also provide current awareness services, tailored periodic reports designed to keep a company's executives or engineers abreast of the latest advances in their fields with a minimal investment of time. Additionally, IAC engineers offer highly skilled assistance in analyzing the information retrieved to the company's best advantage.

For further information on IAC services, interested organizations should contact the director of the nearest center; addresses are listed in the directory that follows.

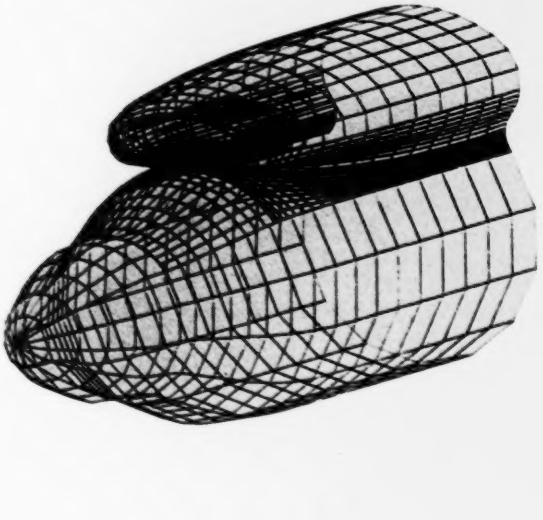
Software Center

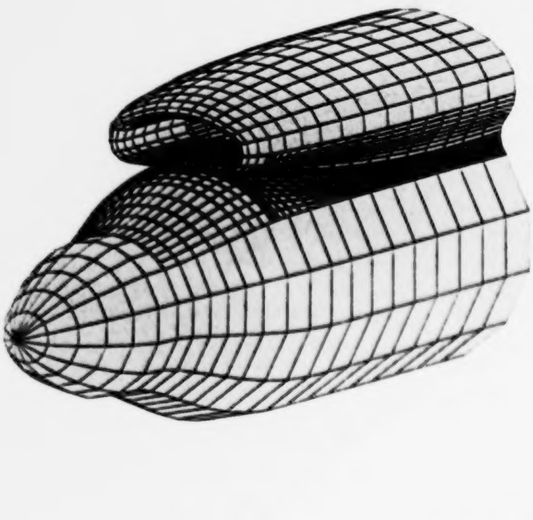
In the course of its varied activities, NASA makes extensive use of computers, not only on Space Shuttle missions but in such other operations as analyzing data received from satellites or deep space probes, conducting aeronautical design analyses, operating numerically-controlled machinery and performing routine business or project management functions. NASA and other technology-generating agencies of the government have of necessity developed many types of computer programs, a valuable resource available for reuse. Much of this software is directly applicable to secondary use with little or no modification; most of it can be adapted for special purposes at far less than the cost of developing a new program.

To help industrial firms, government agencies and other organizations reduce automation costs by taking advantage of this resource, NASA operates the Computer Software Management and Information Center (COSMIC)®. Located at the University of Georgia, COSMIC collects, screens and stores computer programs developed by NASA and other government agencies. The Center's library currently contains more than 1,400 programs that provide computer instructions for such tasks as structural analysis, design of fluid systems, electronic circuit design, chemical analysis, determination of building energy requirements and a variety of other functions. COSMIC offers these programs at a fraction of their original cost and the service has found wide acceptance in industry.

An example of COSMIC's service is its dissemination of a software package known as the Hidden Line Computer Code. Developed by a mathematician at NASA's Ames-Dryden Flight Research Facility, the Hidden Line Computer Code offers a solution to a long-standing problem in computer design. The problem is that a computer does not "see" a solid object as the human eye sees it, but defines the *whole* object without regard to perspective—and therefore produces a cluttered, confusing picture that complicates and slows the computer design process. The Hidden Line program considers whether a line in a graphic model of a three-dimensional object should or should not be visible; it automatically removes superfluous lines and permits the computer to display an object from a specific viewpoint, just as the human eye would see it.

The accompanying graphics illustrate the program's utility. At left below is a computer-generated drawing of an engine nacelle for an advanced turboprop aircraft design investigated by Lockheed-Georgia Company. Created by a conventional program, this graphic has hundreds of extra lines because the computer shows all the lines resulting from its stored input without regard for perspective. Company use of the Hidden Line Computer Code produced clean,

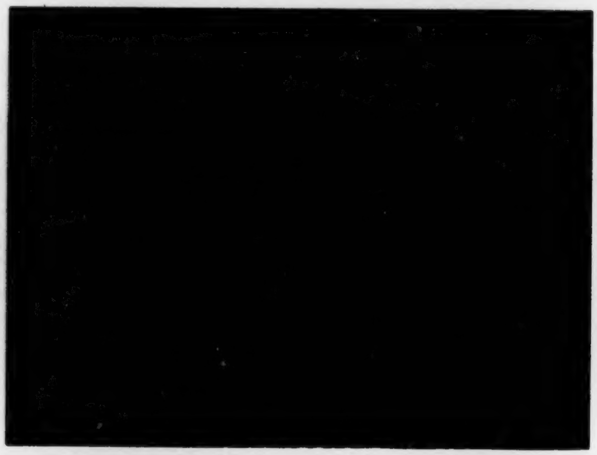




unambiguous drawings like the one adjacent.

Capable of being used in a broad variety of applications, the Hidden Line program is one of COSMIC's "best sellers;" its users number in the hundreds, ranging from small companies to the largest U.S. corporations, and they embrace a wide spectrum of industries. An example is the code's use by the Nebraska Public Power District in construction of the Sutherland, Nebraska power station pictured below.

The program was used for locating the planned construction site; it presented graphics of many different viewpoints, so that engineers were able to determine the most effective design of earthwork and structure to assure that the facility blended with the environment.



Another example is COSMIC's service to United Information Services (UIS), Charlotte, North Carolina, a company that provides computer services to industry. UIS performed a computer analysis for the R.J. Reynolds Tobacco Company, Winston-Salem, North Carolina, which seeks to reduce plant noise levels so that its employees will not have to wear ear protection devices; one of Reynolds' facilities used in cigarette manufacture and packaging is shown below. UIS used a COSMIC-supplied software package consisting of two computer programs—called NOIZ and RAYTR—developed by Virginia Polytechnic Institute and State University. The programs were used to calculate predictions of noise levels caused by the equipment pictured. The predictions enabled engineers to determine accurately the amount of sound absorption required to effect an improved working environment for employees, information used in design of new buildings or renovations. Thus Reynolds—and other UIS clients—can avoid installation of excess absorption, which increases cost but does not further improve the working environment.

A third example is Talley Industries' use of a COSMIC program called MASPROP, developed by Langley Research Center. Located in Mesa, Arizona, Talley Industries is a leading company in rocket propellant research, noted particularly for advances in the application of propellants to aircrew escape systems, such as the military aircraft ejection seat pictured at bottom right. Talley used MASPROP (Determining Mass Properties of a Rigid Structure) to perform calculations needed to determine the center of gravity for a particular thruster, a determination essential to accurate positioning of the motor or generator in the escape system. The company's use of MASPROP replaced hand calculations that sometimes took several weeks; MASPROP reduced the time for each calculation to four hours or less.

To assist prospective customers in locating potentially useful software, COSMIC publishes an annual indexed catalog of all the programs in the center's inventory. Available on microfiche, computer magnetic print tape or in hard copy form, the catalog may be purchased directly from COSMIC. The center also helps customers define their needs and suggests programs that might be applicable. For further information on COSMIC's services, contact the director at the address in the directory that follows.

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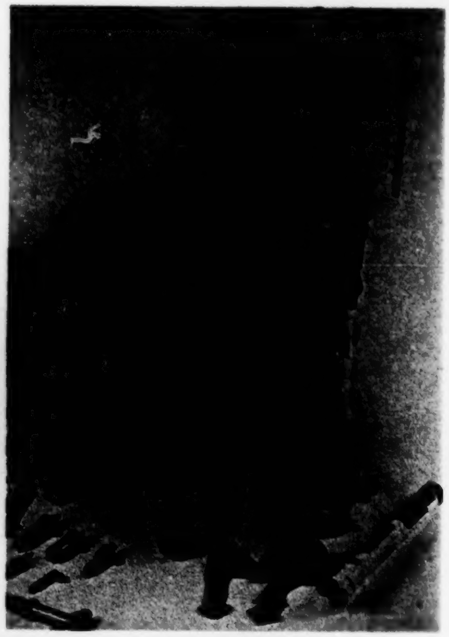

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Technology Applications

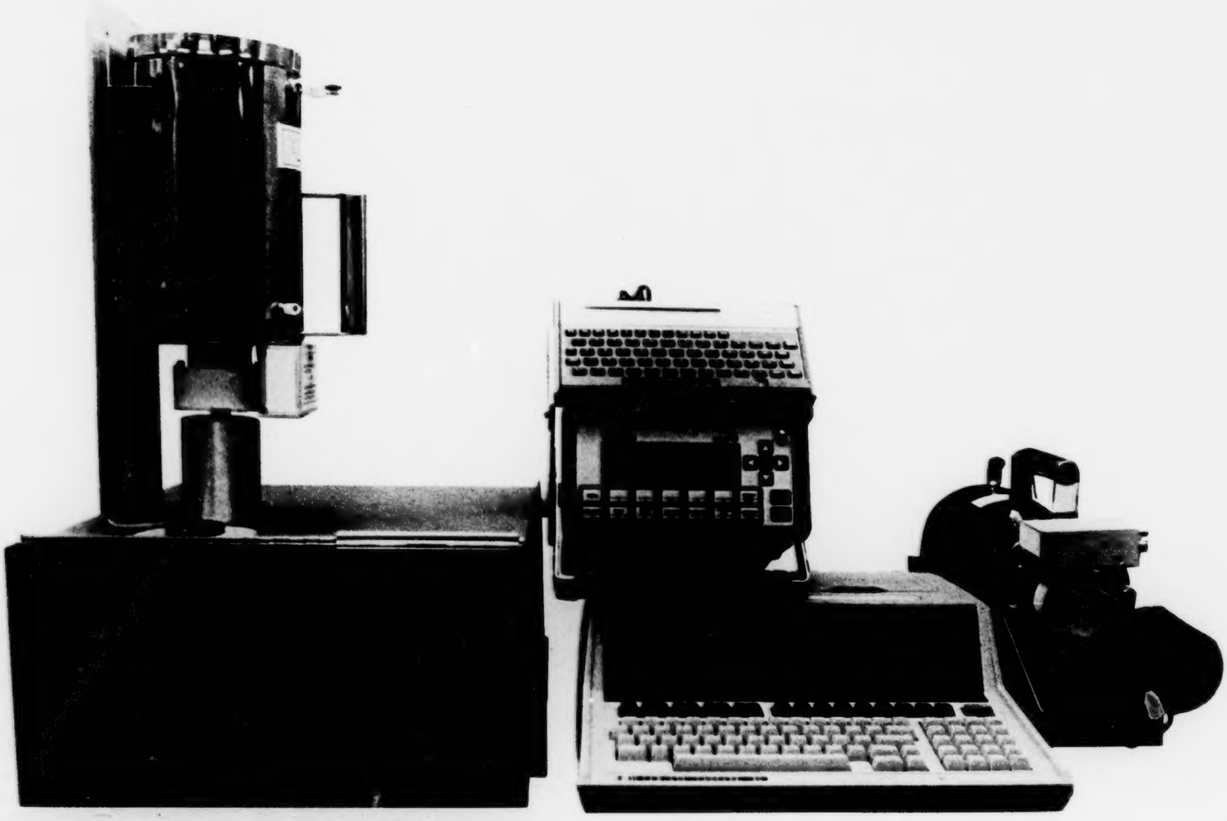
One facet of NASA's Technology Utilization Program is an applications engineering effort involving use of NASA expertise to redesign and reengineer existing aerospace technology for the solution of problems encountered by federal agencies, other public sector institutions or private organizations.

Applications engineering projects originate in various ways. Some stem from requests for assistance from other government agencies; others are generated by technologists who perceive possible solutions to public sector problems by adapting NASA technology to the need. NASA employs an application team composed of several scientists and engineers representing different areas of expertise. The team members contact public sector agencies, medical institutions, trade and professional groups to uncover problems that might be susceptible to solution through application of aerospace technology.

An example of an applications engineering project is the work of Langley Research Center in adapting planetary exploration technology to an Environmental Protection Agency (EPA) need. The original technology was an X-Ray Fluorescence Spectrometer (XRFS) developed for two Viking Lander spacecraft that conducted successful investigations of the surface of Mars in the latter 1970s and the 1980s; the instrument was used for analyzing elements in the Martian soil. Subsequently, XRFS technology was adapted to development of a portable element analyzer for use by Bureau of Mines geologists in field exploration; that instrument is now being produced commercially. Langley is employing XRFS technology in still another application to meet an EPA requirement for a portable water quality and toxic waste monitor. EPA wants an easily transportable system that can be installed in a van or panel truck and conveyed to a lake or stream for on-site chemical analysis of the water.

Shown below, Langley's prototype system consists of four separate modules. The first, pictured at upper left and again at far right to present a different view, is a cryogenically-cooled solid state x-ray detector and a miniaturized x-ray tube; this source and detector assembly can be used alone or as part of the second module, the sample analyzer unit (blue box at lower left). The latter module features a semiautomated filtration operation wherein the water sample is treated with a precipitation agent; the resulting precipitate is filtered and collected on a membrane, then positioned under the source and detection assembly for elemental analysis.

The data is collected in the third module, a portable multichannel pulse height analyzer (center unit in the photo). At the operator's discretion, the data can be



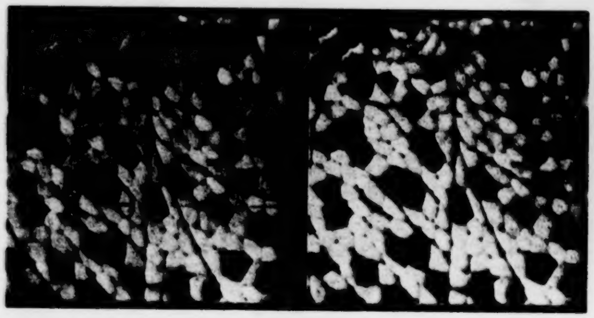
transferred to the fourth module, a computer (bottom center) for analyses and printout of the elements detected and their concentrations. To miminize development time, the prototype system modules were modified from commercially available instruments.

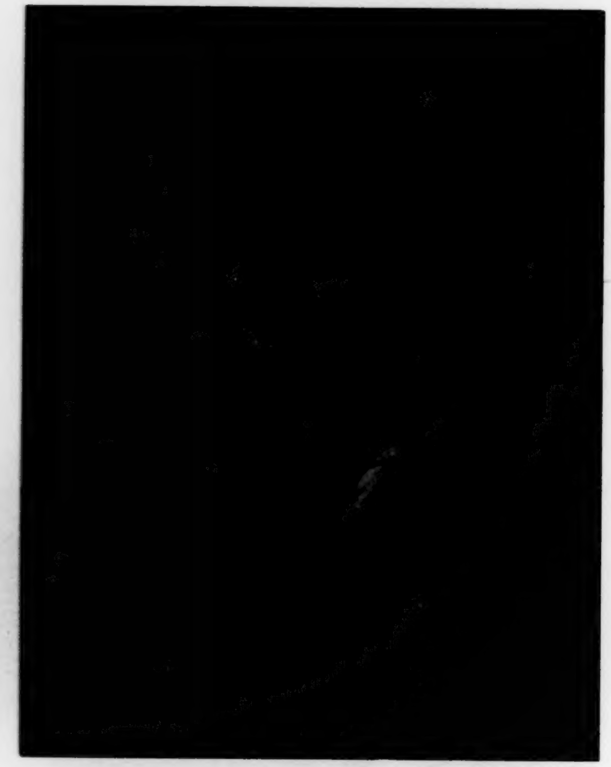
The system allows screening of more than 50 chemical elements, a dozen of which are conventional pollutant elements of EPA interest; priority is given to toxic heavy metals, such as arsenic, mercury, lead, cadmium and chromium. Concentrations as low as 50 parts per billion can be detected. The system will be field tested, under EPA direction, this year.

Another applications engineering example is a digital image processing system, designed and built by Jet Propulsion Laboratory (JPL), that can automatically scan stained fibers of muscle tissue to determine the characteristics of each fiber. Such information is of great value to laboratories engaged in muscle biology research and to hospitals or clinical laboratories for diagnosis, treatment and evaluation of various neuromuscular diseases and paralytic conditions. JPL, with long experience in image processing technology developed for space research, became involved in automated analysis of muscle tissue when observations showed that humans and animals lost some muscle bulk after prolonged exposure to the weightless environment of space. To determine the reduction in weight and size of muscle fibers, JPL developed an image processing technique for analyzing the muscles of rats who had been in space for a lengthy period; that effort provided a base for the current project.

Human muscles can be divided into three categories: cardiac, the heart muscle; smooth muscles that line the blood vessels and the urinary, digestive and genital tracts; and striated or skeletal muscles that govern movements of the body structure and maintain upright posture. The latter category can be further divided into two subgroups: "fast twitch" muscles that contract rapidly and tire easily, and "slow twitch" muscles that contract slowly but do not fatigue easily. Physicians and researchers can distinguish between these two types by means of a staining technique that has been in use for about 15 years. When muscle tissue from a biopsy is treated with certain chemicals, including an enzyme called ATPase, slow fibers viewed by microscope show up light in color while fast fibers are dark. Thus, in cross-section, the stained muscle fibers look like a tile floor, a mosaic of light and dark polygons. The staining technique opened the door to diagnosis of the type and severity of neuromuscular disease by providing a way to count and measure slow and fast fibers—but there remained a problem: the physician's microscopic analysis was subjective and of limited accuracy, and a more quantitative analysis would require about a week of painstakingly tedious effort. JPL undertook to solve the problem by application of its digital image processing expertise.

JPL's project resulted in a compact, automated computer system that conducts quantitative analyses of muscle biopsies quickly, accurately and routinely. The digital image processing device can measure the area, density, circumference and stain intensity of a fiber in about 20 seconds and present to the physician or researcher an easy-to-comprehend histogram relating numbers of muscle fibers to their sizes. The photo at lower left shows a digital muscle fiber image in the left panel and a computer analysis at right. The system can be used for basic research in muscle biology and athletics as well as for diagnosis, treatment and evaluation of such conditions as paraplegia, quadriplegia, myasthenia gravis and amyotropic lateral sclerosis (Lou Gehrig's disease). It is being employed in both research and clinical investigations by the University of California at Los Angeles (below).





NASA's Technology Transfer System

The NASA system of technology transfer personnel and facilities extends from coast to coast and provides geographical coverage of the nation's primary industrial concentrations, together with regional coverage of state and local governments engaged in transfer activities. For specific information concerning the activities described below, contact the appropriate technology utilization personnel at the addresses listed on the following pages.

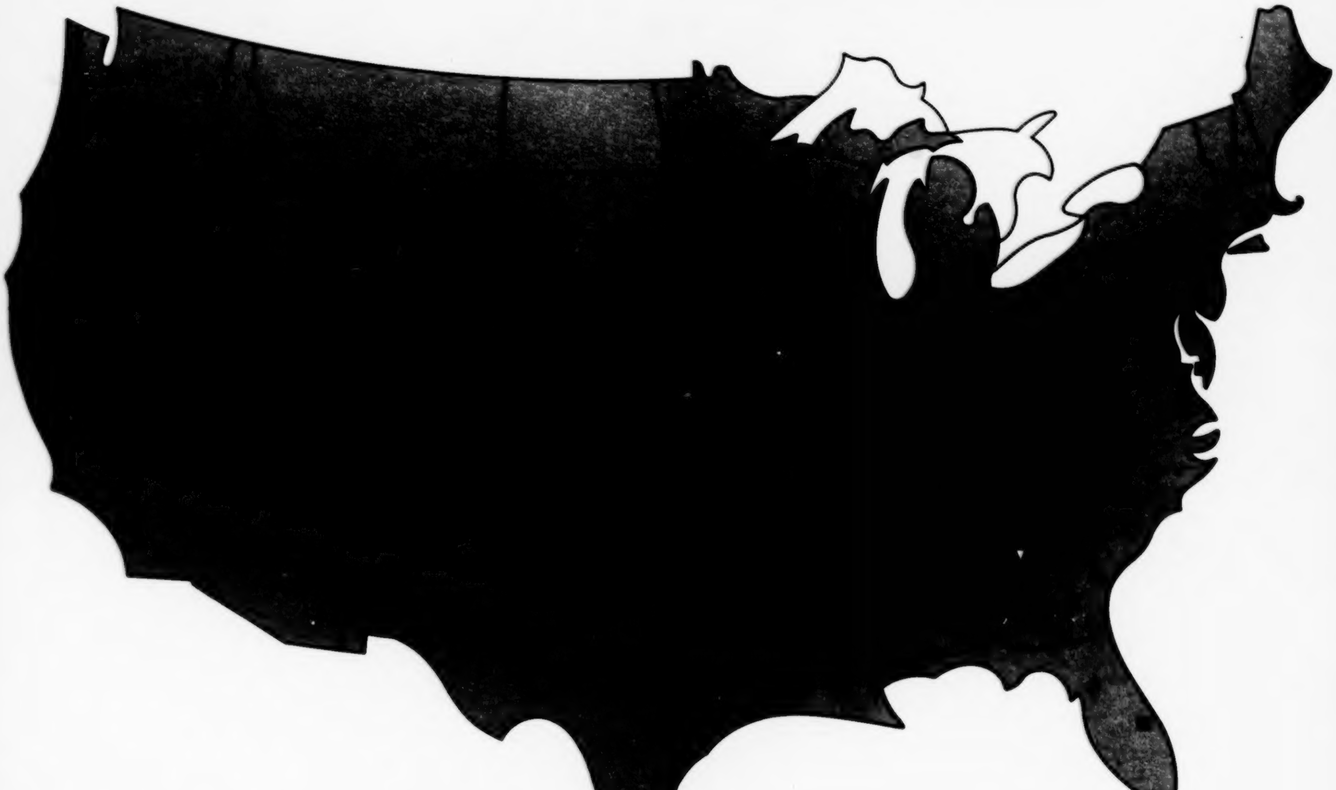
For information of a general nature about the Technology Utilization Program, address inquiries to the Director, Technology Utilization Division, NASA Scientific and Technical Information Facility, Post Office Box 8757, Baltimore/Washington International Airport, Maryland 21240.

■ *Field Center Technology Utilization Officers:* manage center participation in regional technology utilization activities.

● *Industrial Applications Centers:* provide information retrieval services and assistance in applying technical information relevant to user needs.

∇ *The Computer Software Management and Information Center (COSMIC):* offers government-developed computer programs adaptable to secondary use.

▲ *Application Team:* works with public agencies and private institutions in applying aerospace technology to solution of public sector problems.



Field Centers

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, California 94035
Technology Utilization Officer: *Stanley A. Miller*
Phone: (415) 694-6471

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland 20771
Technology Utilization Officer: *Donald S. Friedman*
Phone: (301) 344-6242

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas 77058
Technology Utilization Officer: *William Chmylak*
Phone: (713) 483-3809

John F. Kennedy Space Center
National Aeronautics and Space Administration
Kennedy Space Center, Florida 32899
Technology Utilization Officer: *U. Reed Barnett*
Phone (305) 867-3017

Langley Research Center
National Aeronautics and Space Administration
Hampton, Virginia 23665
Technology Utilization and
Applications Officer: *John Samos*
Phone: (804) 865-3281

Lewis Research Center
National Aeronautics and Space Administration
21000 Brookpark Road
Cleveland, Ohio 44135
Technology Utilization Officer: *Daniel G. Soltis*
Phone: (216) 433-4000, ext. 422

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, Alabama 35812
Director, Technology Utilization
Office: *Ismail Akbay*
Phone: (205) 453-2223

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91009
Technology Utilization Officer: *James T. English*
Phone: (818) 354-3318

NASA Resident Office—JPL
4800 Oak Grove Drive
Pasadena, California 91109
Technology Utilization Officer: *Aubrey D. Smith*
Phone: (213) 354-4849

National Aeronautics and Space Administration
National Space Technology Laboratories
NSTL Station, Mississippi 39529
Technology Utilization Officer: *Robert M. Barlow*
Phone: (601) 688-1929

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Kerr Industrial Applications Center
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Durant, Oklahoma 74701
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NASA Industrial Applications Center
823 William Pitt Union
Pittsburgh, Pennsylvania 15260
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NASA Industrial Applications Center
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Robert Mixer, Ph.D., director
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New England Research Applications Center
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Storrs, Connecticut 06268
Daniel Wilde, Ph.D., director
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North Carolina Science and Technology Research Center
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Research Triangle Park, North Carolina 27709
James E. Vann, Ph.D., director
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Stanley A. Morain, Ph.D., director
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Southern Technology Applications Center
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J. Ronald Thornton, director
Phone: (904) 392-6760

NASA/UK Technology Applications Program
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Lexington, Kentucky 40506
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Computer Software Management and Information Center

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Athens, Georgia 30602
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Commercial Space Programs

Headquarters, National Aeronautics and Space Administration
Office of Commercial Programs
Commercial Programs Division
Washington, D.C. 20546
Gary E. Krier, director
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Scientific and Technical Information Facility

Centralized Technical Services Group
NASA Scientific and Technical Facility
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Baltimore/Washington International Airport
Maryland 21240
Manager, Technology Utilization Office: Walter Heiland
Phone: (301) 859-5300, extension 242

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